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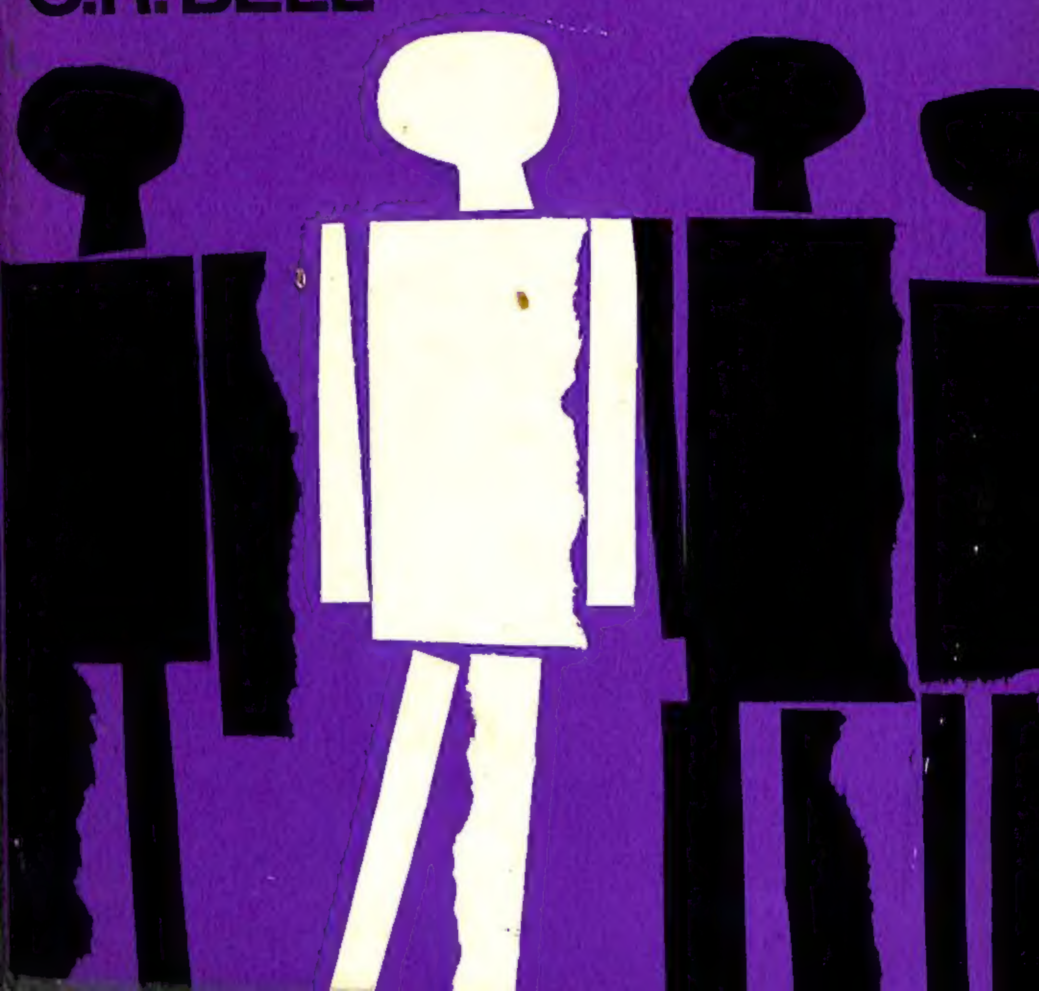
Men at Work

C.R. BELL



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4 MEN AT WORK

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Men at Work

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For Mark and David

PREFACE

It happens sometimes that an author's first thoughts about a book, which he has been invited to write, give rise to aims that are unrealistically over-ambitious. This pitfall is perhaps most likely to occur when the book is to be the first attempt by the author to draw together the 'random jottings' that have been accumulating in his mind for a decade or more. I fell into such a trap. I saw, and see still, the need for a book which would integrate the diversity of approaches to the study of the effects of various environmental factors on the efficiency and well-being of men at work. It does seem to me that, whilst there are many publications that give adequate accounts of the effects of *either* physical environments, *or* organisational environments, *or* social-psychological environments on men at work, there has been a dearth of attempts to explore how variables from these three categories interact. If the abyss that, I feel, exists between the expertise of ergonomists, sociologists and social-psychologists is real, then someone ought to be thinking about a bridge-building endeavour.

This was my original aim. With the benefit of hindsight, I can see now that such bridges might be erected within a 10,000 word essay or within a 200,000 word tome. Between these two extremes of crisp ideas and comprehensive data, one is in danger of disappointing the reader who expects either. I should like to take this early opportunity to apologise to those readers who may suffer this kind of disappointment. I hope that it will not be long before someone is found who has the insight, the skill, and the time, to produce an integrated account of the diversity of forces that act upon man at work to promote the rich variety of his responses.

In this book I have concentrated upon the interactions between man at work and aspects of his physical environment. My interest in ergonomics, which this approach reflects, was fostered over many years of full-time research in the Medical Research Council by the Director of its Environmental Physiology Unit, Pro-

fessor J. S. Weiner, and by one of my former colleagues who has subsequently been appointed to a Chair of Psychology in Australia, Professor K. A. Provins. I owe much to both of them for their tuition and encouragement.

Since I finished full-time research and retreated from its demands into the sanctuary of academia, I have enjoyed the privilege of being able to explore the wider aspects of men at work with undergraduate students at the University of Manchester and with post-graduates at University College, London. These explorations have brought into the open some of the doubts I had held covertly about the adequacy of attempts based solely upon an ergonomic approach to gain an understanding of the influences on men at work. I have tried to express some of these doubts in this book. Many of the statements I have made, it must be admitted frankly, reflect relatively uncrystallised feelings rather than the kind of well-substantiated conclusions that would stand up to cross-examination in a scientific court of law. At best, I hope that the opinions I have expressed may find echoes in the thoughts of some of my readers. At worst, I fear that they may be dismissed as ill-considered. In the data-based empiricism of the tradition of psychology in which I was nourished, the intuitions that I have allowed myself in this book may be presented only as poor things but they are my own.

The editor of this series, Advances in Psychology, Professor J. Cohen, has been most kind in his advice and encouragement. I am keenly appreciative of his confidence and help. I hope that my attempts to communicate my feelings about the constraints on limited approaches to the study of man at work will be judged by the reader to represent an advance on those texts in which such questions are seldom articulated. The faults and inadequacies of what follows are ineluctably mine. I do sincerely crave the indulgence of those who become disappointed by what they read here.

CLIFF BELL

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CHAPTER 1

Introduction

A wide variety of investigators has studied many aspects of men at work. Several disciplines, in the humanities, in medicine and in the behavioural sciences, have made unique contributions to our understanding of the problems of men at work in modern, industrialised societies. Though interest in this research topic has been growing during the last 100 years or more, it was given an added impetus in those countries that were involved in the conflicts of two world wars. The relation of men to their physical, organisational and social environment became an urgent concern of applied sciences during these times when the achievement of high productivity among civilian workers and of high efficiency among fighting men was at a premium. Increases in the numbers of studies of working man matched the accelerated growth of research in other fields of scientific enquiry related to the successful pursuit of war.

Since the beginning of the second half of the twentieth century there has been a marked resurgence of interest in industrial research. There appear to be at least three factors which may be responsible for the present impetus to studies of men in relation to their work environments. First, advances are taking place in the degree of technological sophistication of many industrial processes. When these occur, there are considerable increases in capital investment demands. The two concomitant influences of the installation of expensive equipment and the reduction in the labour force needed for its operation serve to emphasise the need to achieve a 'fit' between man at work and the environmental conditions within which he operates. Industrial design

for these conditions seeks to produce maximum efficiency at the man-machine and man-environment interfaces. Levels of inefficiency that may be tolerated in older, labour intensive, industries may be intolerable, being too costly in lost production, in more technologically advanced industrial contexts. Where the causes of inefficiency are remedial through improvements in design, considerable pressure may arise to support scientific research studies that produce recommendations about the ways in which financial losses may be reduced.

Second, in recent years there has been a growth in the power of workers' associations and trade unions. If this growth continues, it may not be long before such bodies become the sponsors of investigations into the organisational environment of men at work. With greater participation in decision making and negotiation affecting many aspects of industrial activity, it may be necessary for more information to be obtained relating to the effects of organisational structures and procedures on such activities. There has already been a great deal of enquiry into the organisational aspects of industry. So far, however, the research has been directed to meeting the needs of employees at the managerial level and the demands of communications experts. With participation by other workers and their trade union, or employee association representatives, in the day-to-day running and forward-planning of industrial concerns, there may be an increase in the frequency of studies of organisational environments that will be more closely directed to the interests of those who have recently acquired the responsibilities of industrial decision making.

A third contributory influence on a resurgence of studies of men at work is based upon a growing awareness of the need for giving adequate training to managers whose skills, or lack of skills, may have repercussions in many departments of megalithic international companies. 'Human relations' skills, negotiating skills, organisational skills, economic planning skills, and many others, acquire even greater importance as industrial concerns become more complex. There are probably few surviving owner-managers in many sectors of industry today who are able to rely on their intuition and the precedents of their forbears. As

industry changes, so the demands on its managerial employees change. It is likely that these demands may be the springboard for much future research into industrial sciences.

In a somewhat paradoxical way, the beginnings of a new interest in studies of men at work has coincided with the emergence of a research endeavour which may become, eventually, an equally important preoccupation of scientists. This is an awakening of interest in the study of leisure-time activities. The problems confronting men at retirement from full-time work have been investigated sporadically over the last quarter of a century or more. An acknowledgement in some sections of industry, and in some governmental welfare agencies, of society's responsibility for providing assistance for the worker in his transition from employment into retirement has already produced several schemes of pre-retirement counselling and training. Preparation for retirement and adjustment to a life without the demands of full-time work will no doubt continue to be the topics of study of some applied research in the human sciences. There is, however, a parallel realisation dawning that there may be similar problems of adjustment to be made by those workers who have three or four days leisure forced upon them through the reduction of the length of a normal industrial working week. The next few decades may well see the development of the study of problems that may arise through man's need to adjust to leisure.

Over the foreseeable future, however, it is probable that work will retain its significant part in the lives of the great majority of members of industrialised societies. Studies of the behaviour of men at work and of the effects of the industrial environment upon workers' well-being and efficiency will continue to increase in frequency and complexity. There is much still to be done. Scientists of many disciplines have already contributed something to the growth of knowledge of men at work. What has been produced has been a body of knowledge that is satisfactory in patches rather than being uniformly or comprehensively informative. Some of these patches of knowledge, and the gaps that exist between them, will be explored in this book.

I *Descriptions of Industrial Environments*

Accounts of environmental influences upon men at work have varied in the breadth of their approach. At one extreme, there has been the specification of a narrow aspect of one environmental variable and its effect upon a single type of response. At another extreme, there has been a general description of classes of industrial environmental variables and classes of workers' responses. An example of one type of account might be a case-study approach that leads to a descriptive enumeration of the myriad factors that have produced a 'high-flier' employee who rises from tea-boy to general manager in the time taken by a 'low-flier' to complete his probationary period of employment. Many environmental influences on 'high-flier' work performance may be cited in a study. These may range from a particular regimen of breast feeding or toilet training during his earliest years, to the influence of a particular school-master who had been admired, to one or more experiences of mystical states, to the sublimation of a constant over-stimulation by libidinal forces, to a marriage to a consistent mother-surrogate, to the successful completion of an officer training scheme, to the charismatic effect his personality has on other people. Though such studies may reveal the significant variables in one person's life, they may say little about the significant influences on the hierarchical advancement of other men at work. An example of a broad approach might be an overwhelmingly general theory of the interaction of men at work with prevailing social and economic conditions that may lead to a prediction of 'alienated' or 'anomic' behaviour among the 200 million or so workers in Western European industries. Such a theory says little about the variety of forms of behaviour produced by workers in particular social and economic conditions. Nor does it give very much hope for management in particular firms being able to infer, from the theory, the courses of action they should take to improve the conditions in their own factory, department or office to avert the consequences predicted by the theory.

The scientists whose research is considered in the middle chapters of this book have tended to concentrate their attention

upon *one* aspect of the physical environment of man at work and on the ways in which that may affect *one* component of the worker's performance or *one* feature of his health or well-being. A broader definition of working environments, and sometimes a much less precise delineation of their effects, is more characteristic of the research considered in Chapter 6. In those studies, greater attention has been paid to social and psychological aspects of industrial environments. Extraordinarily few studies have attempted to take account of physical and non-physical environmental variables acting in concert.

It could be argued that no study has yet appeared in which the total environment of man at work has been identified. There may have been, in the majority of studies of industrial situations, an inadequate description of the environmental factors *at the place of work* that may affect men's performance or well-being. This inadequacy of environmental description is even more pronounced when one considers the possibility that factors *outside* the immediate work context may be influential too. Factors that have usually been ignored by investigators are the possible influences of the worker's domestic experiences before he leaves home for work; the environmental conditions of his journey to work; the social milieu established as the worker is greeted by his fellow workers, by his subordinates, by his superiors; the conditions under which he takes his mid-morning, mid-day, and mid-afternoon breaks; or the experiences he anticipates after completion of his day's work in the factory or office. Anecdotal evidence suggests that some of these factors may be influential in determining how the worker feels and how he performs at his place of employment. There has been, however, almost no systematic study of the effects of extra-work environmental factors on work performance. In most studies, the variables included do not add up, by a long way, to anything like a description of the worker's total environment. The extent to which these apparent deficiencies in environmental descriptions make research studies inadequate depends closely upon the extent to which the investigators have restricted their research aims. Most of the studies described in subsequent chapters of this book have had very restricted aims and many of them make

explicit reference to the limitations of their general conclusions. In these restricted investigations, it is usual to assume that the environmental variables which have not been considered are of less significance than are those environmental factors which have been highlighted. Such an assumption may not always have been justified.

II *Varieties of Work*

Very few of the several thousand different jobs in a modern industrial society have been studied in any detail by those who attempt to establish relations between the physical environmental conditions of work, on the one hand, and its efficiency, on the other. Most of the jobs that have been chosen for study occur within large institutional organisations such as the civil service, the steel industry, the mining industry, or the armed forces. More often than not, the jobs chosen for study have been selected by higher levels of management rather than by the workers themselves or by their trade union representatives. Frequently, the investigator has been regarded as a 'problem solver'. His assistance is called for only after sufficient evidence of the adverse effects of some aspect of the working environment on productivity has accrued to convince management that expert outside help is needed.

If the purpose of the study of man at work in relation to the various parameters of his physical environment is to establish general laws describing these interactions, a wider sampling of industrial environments and the jobs performed within them is necessary. We may be witnessing a growth in the number of industrial case-studies, in which the solution of a particular problem is sought. However, far more of these will be needed before some general theoretical framework can be sketched than if there had been a growth in the number of knowledge-seeking enquiries into the nature of the working environment and its effects. Such enquiries have been very much a minority among the studies of men at work. Most of the research reported so far has had a much more immediate purpose than increase in knowledge *per se*. It has been conducted because there was a

particular problem to be solved at a particular time in a particular set of industrial circumstances. The variety of problems that has caught the attention of management, places an important limitation on the variety of jobs that has been studied.

If members of the public were asked to guess which sections of occupational life had been most thoroughly studied with respect to likelihood that the physical conditions of work would produce danger to the efficiency and well-being of the workers, they might reasonably assume that outdoor occupations would appear high on the list. They would be wrong. In fact, although there are some notable exceptions to the general rule, outdoor workers have been largely ignored by applied scientists. Some research has been reported on the design of protective clothing against cold, wet, windy outdoor working conditions. But compared to the efforts made in achieving a suitable design of protective clothing for furnace-men, fire-fighters, rescue personnel, trawlermen and a few others, the amount of study devoted to the provision of adequate clothing for most outdoor workers is small. It is rare to find reports of systematic studies of the effects of exposure to their physical environments on the health, well-being or efficiency of, for example, farm workers, postmen, milkmen, steeplejacks, sportsmen, porters, builders, gardeners, street-cleaners or road-menders.

The effect of their physical environment upon the work of members of service industries has received less attention from investigators than has the effect of such variables upon work in manufacturing industries. Very little study has been made of the effects of working environments in banking, teaching, shop work, maintenance and repair, communications, laundries, clerical, executive or administrative work in the civil service, transport or entertainment. Light industry is less well represented in the research literature than is moderate or heavy industry. Less is known about the effects of environmental conditions upon the performance of management than upon the performance of those whom they manage. It is more difficult to discover how environmental conditions may affect the efficiency of applied scientists than it is to discover how the efficiency of those whom the scientists study might be affected. Many enquiries have con-

centrated upon effects of exposure to adverse environmental conditions on individual workers. Relatively little is known about the effects of such conditions on the performance of jobs that require men to work co-operatively in gangs, groups or committees.

The many types of work that have not been studied are not lacking in problems. Environmental conditions that have not been studied are by no means invariably innocuous. The narrow selection of jobs for study is not an indication of the range of hazardous environments. It is just as much an indication of the tremendous disparity that exists between the range of occupational life in an industrialised society and the relatively meagre scientific effort made to investigate it. The proportion of the gross national product devoted to the study of the conditions under which that product is achieved is probably minuscule in most industrialised societies. The limited variety of jobs investigated, however, is determined not only by restriction of resources for research but also by the ways in which science and industry interact.

Research into occupational environments, and their effects upon workers, does not follow a planned, systematic infiltration of all parts of industry. It more likely takes the form of a series of *ad hoc* studies based upon specific requests for limited information related to the solution of particular problems that have been identified and described by individual managements. These are more concerned with getting an answer to their question than with advancing scientific knowledge along a wider front.

III *Varieties of People*

If someone could be found who had the time and application to scrutinise the samples of people who have participated in studies of the effects of physical environmental variables on performance and well-being, some extraordinary results might emerge. One strange outcome of such an enquiry would be that if the people who have provided data were taken to represent all those who work for a living, one might conclude that there are no female workers. It is true that there have been a few

anthropometric studies and some 'thermal comfort' studies of women. In general, however, most investigations of the effects of environmental variables and working conditions on the performance and well-being of workers have completely ignored the presence of women at work. This has been true of both laboratory and field investigations.

A case might be made to the effect that this under-representation of women is unimportant because any differences between men and women in their responses to environmental variables are negligible. If this were so, then, at least from a scientific point of view, it would not matter if general conclusions about worker responses were based on data collected from male rather than female participants in research. Unfortunately, there is a lamentable lack of evidence in the literature to decide whether or not male and female responses to environmental factors at their place of work vary significantly. It is not easy to be sure why there is so little evidence on the differences, if any, between men and women in their occupational responses to their environments. Why there have been so few studies of women workers is a question that may be answered satisfactorily perhaps only when someone has investigated the investigators. Until more is known about the possibility of a differential susceptibility of men and women to environmental influences at their place of work, it must remain sufficient to bear in mind that the studies described in later chapters have often failed to include females among the variety of workers studied.

There are other potential restrictions on the representation, in the literature on the subject, of the diversity of workers. The source of one of these restrictions lies in the possibility that workers' reactions to some features of their industrial environments may change as historical circumstances change. It has been argued, for example, that some of the data collected in the studies described in Chapter 6 have become out-of-date because the political and economic conditions that prevailed at the time were determining factors that have since changed markedly. The argument is made that conditions of full employment, strong trades unions, economic growth and a stable community of workers both inside and outside the factory may pro-

duce quite distinct responses to some aspects of the physical and organisational environment of men at work. Different responses may be found in times of widespread unemployment, ineffectual trades unions, economic recession and a shifting, unstable labour force. Such changes may occur in an industrialised nation over periods of not much more than a decade or two. If changes of this kind do affect the type of worker responses, the people studied in one set of conditions will not be adequate representatives of workers in changed conditions. Very few studies of men at work have been repeated in changed economic, political and social climates. The variety of people studied twenty or thirty years ago, therefore, may be quite different in some respects from the variety of people in industry today.

Another difficulty in adequately representing the variety of people in their industrial contexts is that of reflecting, in the investigation, the ways in which workers may be shaped in their responses by the routine performance of their job over a long period, for most weeks in each year, for five or six days each week, and for eight or more hours each day. Many studies have been based upon data provided by workers who have been invited to a laboratory and asked to perform a newly-learned task for periods of perhaps an hour or less. When this happens, there may be a far-from-accurate simulation of the conditions of performance that actually occur at the place of work, and people in the context of the investigation may not reflect the characteristics of people in the real work context.

Applied research is usually conducted in one of two locations. Either the investigator will go to the factory or the workers will go to his laboratory. In the former case, the investigator may sample the behaviour of workers as they go about their normal daily routines. This direct observation is not always possible or scientifically desirable. On some occasions when it appears that the scientist is conducting his field-work within the factory, it may be that he is in fact conducting 'laboratory' research but away from his laboratory. These occasions arise when management feels that the investigator might interrupt productive processes by his presence or when the latter feels that the actual work environment may contain too many so-called 'confounding'

variables. Both these difficulties may be resolved by the provision of special facilities for the investigator in the form of a suite of rooms set aside for his task. This effectively means creating laboratòry conditions. Workers who provide data under such conditions do so through their participation in a laboratory exercise.

Whether the scientist operates within the context of the management's laboratory or his own, his task will be to attempt to simulate the 'significant' features of the real work situation. Such simulation is necessary if the data that are collected are to be related to the real work context. The question of the ways in which investigators strive to produce adequate simulations by identifying 'significant' variables is an important one. It is salutory to note, however, that on some occasions a 'simulation' study may be set up in a laboratory after only one or two brief visits to the workshop itself. But even if the investigator is able to achieve an adequate representation of a *work routine*, he is still faced with a simulation problem. This is the problem of simulating, in the laboratory, the characteristics of the *worker at his place of work*. In so far as the investigator fails to reproduce, in the laboratory, the characteristics of people on the shop-floor, a danger remains that the variety of people who provide data will differ from the variety of people to whom conclusions and recommendations derived from the research in question are intended to apply.

Sufficient research material is available to suggest that people who volunteer their participation in research may differ in some of their personal characteristics from those who do not participate. Whether these differences will make for poor representation of worker populations will depend upon the extent to which the differences occur in characteristics that are closely related to the particular interactions of environment and behaviour that are being investigated. For example, an investigator may wish to find out the degree to which co-operative job performance is affected by exposure to environmental noise. It may happen that the workers who volunteer to participate in the study are keen to do so because they are especially sensitive to the effects of environmental noise. Perhaps they hope that

the research will provide help in making a case for the removal of this particular source of stress from their working environment. Because of their special sensitivity to noise, they may produce data in the laboratory that may be quite unrepresentative of the data that would have been produced by their fellow workers who did not care sufficiently to volunteer to take part in the study. If the scientist were to judge the workers in a particular industry on the basis of his observations of these sensitive 'data-providers' he would probably under-represent the range of sensitivity to noise in the original population. Similarly, a distortion of the variety of people at work may occur when those who volunteer to participate in the investigation are more tolerant of environmental stress than those who do not provide the investigator with data.

Not all characteristics, which differentiate between those who provide data and those who do not, will lead to a misrepresentation of the worker population. There is evidence to suggest, for instance, that volunteers for participation in some kinds of study are more sexually adventurous than those who do not volunteer. If an investigation is conducted into, say, visual acuity at low levels of illumination and participants are different in their sexual behaviour from non-participants, this difference has no bearing on the research provided that the determinants of sexual behaviour have no influence upon visual acuity at low levels of illumination. Although many reports have appeared on volunteer characteristics, there is not, as yet, enough evidence to permit an investigator to decide, in advance, whether the research into men at work, that he intends to conduct, will attract a particular type of volunteer or whether the data collected in the investigation will have been distorted by the use of such volunteers. All that he is mostly able to do is to be aware of the potential danger of using volunteers. If the distortion of data does occur, the range of workers in industry will not have been represented by the variety of workers who have taken part in the investigation. The danger of misrepresentation may be exacerbated when research occurs in a laboratory. Factory workers may be reluctant to take part. There may only be available volunteers from among students, fellow-scientists,

technicians or men who are unemployed. In such circumstances, it may be exceedingly difficult to achieve a representation of the variety of worker characteristics as they occur in everyday life in many parts of industry.

IV *Establishment of Environmental Limits*

Employers may tend to assess the effects of physical environmental variables in terms of loss of productivity rather than in terms of a loss of well-being among workers. It may be true, of course, particularly in more extreme environments, that a loss of workers' productive efficiency may be closely, and obviously, associated with their reduced well-being. In less extreme environments, however, it may be that the connection, if it exists, between loss of well-being and loss of efficiency may be much less direct. A host of intermediate variables may occur between measurement of environmental variables and measurement of performance variables at the work-bench. Factors such as labour turnover, sickness rates, absenteeism, accidents or disputes, may seem more directly the outcome of exposure to inappropriate environmental conditions than deterioration in performance as such. Adverse effects of the physical environment may act upon some components of worker performance and not on others. It is sometimes possible for a skilled worker to hide the adverse effects of the work environment on his efficiency by reorganising the elements of his job whilst maintaining his general level of performance. The worker may not always be aware of many subtle effects on his performance of the environment in which he works. The fine analysis and control of the various component parts of the performance of a task that is possible in an investigation conducted in a laboratory will rarely be possible in a shop-floor analysis. In the factory, it is often only when gross effects on productive efficiency have been demonstrated that management will become aware of the need for setting limits to the environmental stresses upon workers. In the laboratory, the particular mode of action of specific environmental variables on individual task components has been the topic of most studies designed to establish stress limits.

Investigations by ergonomists and by experimental psychologists have sought to identify those limits of environmental stress beyond which a significant deterioration in task performance occurs. They have sought to identify those aspects of efficiency in performance that are most sensitive to the influence of particular environmental factors. The point at which any disruption of efficiency becomes 'significant' depends closely, of course, upon the nature of the task being investigated and the context within which the study is undertaken. If the context is a laboratory one, 'significant' effects may be of quite a different order of magnitude from the 'significant' effects that may be identified under actual workshop conditions.

A dilemma is ever present in many fields of applied science and technology. Investigators must often choose between controlled, discretely quantifiable studies in a laboratory and the richly complex studies of relatively uncontrollable and only grossly quantifiable variables in real-life situations. They may be very aware that there are considerable advantages and disadvantages to either choice. Unfortunately, it is not always possible for the investigator to combine the two choices and achieve the advantages of both. If he opts for the laboratory, his enquiry may lead to conclusions that achieve the degree of statistical significance required for publication in a learned journal. But they may be unconvincing to management. Conclusions drawn from studies in industry itself tend to be less precise, statistically, and their significance may be assessed in economic terms. Whether or not management becomes convinced that something important has emerged from a study will depend upon many factors that have little to do with the scientific sophistication of the enquiry. For an investigator of the effects of environmental influences upon the performance of workers, the dilemma is sometimes keenly experienced. Should he aim for the achievement of the precision that a laboratory approach may yield or should he attempt to encompass the realistic complexity of the actual world of industry outside the laboratory? In fact, most scientists try to identify the 'crucial' variables among causative factors and among a range of possible effects, whether in an industrial context or in a laboratory

simulation of it. The difficulty is, of course, that the investigator may often find it very difficult to guess which variables will, in fact, turn out to be crucial in the delineation of environmental limits.

V *Theoretical Models of Man*

Each human science selects one feature of man for study. A non-specialist who looks through the literature of each branch might be forgiven for gaining the impression that many scientists take a rather narrow, blinkered, or even distorted, view of the nature of man. What the outside reader may fail to appreciate is that many scientists, whilst concentrating their attention upon one aspect of man's nature, do not claim that their 'view' represents the totality of man or even some essential elements of his nature. What is being asserted, without its being necessarily made explicit, is that whilst no feature of man exists or functions in isolation from many other of his characteristics, it is possible, and perhaps desirable, to concentrate effort upon the study of one feature at a time. A narrow approach, such as this, is made in the knowledge that sister disciplines are concentrating their endeavours on to different features. There is a covert assumption, or hope, that there will always be sufficient research at discipline boundaries to promote a gradual synthesis of what are initially disparate elements in the study of man. Research in ergonomics, for example, concentrates on certain physical and mental aspects of men at work. The view is taken that it is important to discover the way man functions anatomically, physiologically, and as a processor of information. With this knowledge, ergonomists can give advice about how work could be designed so that features of the environment, machinery and operatives would be integrated into the contextual whole of a smoothly-run *system*. Many studies of the effects of environmental conditions upon the well-being and performance of workers have reflected this point of view.

Systems, whether biological, mechanical, electronic, economic or social, require specified conditions to prevail for malfunctioning to be avoided. The delineation of the limits of these con-

ditions, in respect of the avoidance of malfunction in men at work, has occupied much effort in ergonomics. Systems have also been considered, however, in relation to the conditions in which maximal efficiency of functioning might be expected. From the point of view of man as a component in a work system, therefore, it is not surprising that some attempts have been made to specify the environmental conditions within which man might be expected to function with maximal efficiency. There is little evidence in the literature, unfortunately, to suggest that such ventures have been particularly successful.

The lack of a description of the environmental conditions that would ensure most efficient performance may be due to the fact that present day industrial conditions are so appalling that it has been necessary for research effort to be concentrated upon eliminating hazards. Perhaps, too, there has been too restricted a sampling of the environmental variables that might promote maximal efficiency. Possibly, scientists in those disciplines that have successfully used a 'system component model' of man at work, in order to improve his working conditions and set environmental limits, have tried to extend the analogy of man as a system component too far. For setting of limits beyond which deterioration in performance and well-being occurs, the 'system component model' of man may be quite appropriate. For establishing the conditions under which man may function at his best, the 'system component model' may be inappropriate.

How often there has been in science an extension of analogies of man with another species, or with chemical interactions, or with computers, beyond their original context and their immediate usefulness and with what results would be an interesting research topic. It may happen that this kind of extrapolation beyond the original insight will lead to eccentric, wasteful but innocuous, research into blind alleys that may last a lifetime. Sometimes, it may lead to the diversion of research resources from socially significant problems, amenable to solution, towards those games, beloved by some intellectuals, in which the derivation of meta-solutions to meta-problems is sought in a meta-science. In ergonomics, perhaps a search for the physical environmental conditions that would promote efficient performance

ought to be abandoned and research effort redirected towards a more wide-range identification of environmental limits. Limits of stress from environmental variables in combination need much more investigation. There may be a crucial relation between increasing inefficiency of performance at some industrial task and the physical environmental conditions under which that task is performed. The achievement of better-than-average performance of industrial tasks may depend more closely on variables other than those that form part of the physical environment of men at work.

VI *Other Environmental Hazards*

There are some hazards in the physical environment of men at work that have not been discussed in any detail in the remaining chapters. They are of a more specialised nature than the hazards associated with the lighting, noise, space and temperature aspects of workers' physical environments. The risks they impose on workers are no less severe than some of the risks discussed in the next four chapters, but they have received less attention from all but the most specialised research workers. Industrial psychologists and ergonomists have paid less heed to the presence of these hazards than have occupational hygienists and physiologists. A feature of future psychological study of men at work in relation to their physical environment may be the incorporation of new variables into the investigator's picture of significant influences on performance and well-being. These aspects of industrial environments are vibratory forces, in terms of amplitudes and frequencies; high and low atmospheric pressure levels, with or without changes in oxygen concentrations; acceleration and deceleration (G) forces; and noxious or toxic atmospheric contaminants of either gaseous or suspended-particle types. The aim of research into the effects of these variables has been to provide the worker with protection from discomfort, inefficiency in performance, physiological or medical distress, or from death. The vast majority of reports has been devoted to the establishment of safe limits of exposure against one or another criterion of protection. Details of these studies

may be found in texts that are more specialised and comprehensive than the present one.

In each of the next four chapters one aspect of the physical environment of men at work is examined at a time. In Chapter 2, consideration is given to the lighting, illumination, vision and glare aspects of working environments. Chapter 3 examines the effects of noise, both wanted and unwanted, on men at work. Chapter 4 discusses the spatial requirements of men at work and the relevance of anthropometric studies to the design of work-places. In Chapter 5, effects of the temperature characteristics of working environments on men at work are examined. It may have been more satisfactory from some points of view to have arranged the next four chapters on an industry-by-industry basis so that greater emphasis could have been given to the fact that variables rarely occur in isolation from each other in the world of industry. Unfortunately, the present state of knowledge is insufficient for such an industry-by-industry 'total environment' approach to be adopted. It will only be after a great deal more research has been reported that it may be possible to give an adequate account of the ways in which several environmental variables, in the combinations that typically exist in real life work situations, affect the well-being and performance of the workers who are exposed to them. For the present, the reader is invited to remind himself that, as one feature of the physical environment of men at work is being discussed, other features have not suddenly and mysteriously become innocuous in many industrial contexts. Similarly, effects on well-being and performance other than the ones being examined in any given investigation, do not become negligible or insignificant, magically, because no one seems to be paying attention to them at the time.

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CHAPTER 2

Lighting

Some of the variables in the environment of men at work that impose stresses upon workers take the form of waves of energy. Waves of compression and expansion travelling through the air around him impose noise stresses upon the worker. Waves of energy transmit thermal stresses to man. In this chapter, the effects on man at work of those waves of electro-magnetic energy that are defined as visible light will be discussed. The interaction of man and the lighting, or illumination, aspects of his physical environment is studied in order to determine (i) the levels of illumination needed for man to see adequately; and (ii) the limits beyond which he may be functionally or physiologically blinded.

I *The Visual Stimulus*

A sensation of light is evoked when electro-magnetic energy stimulates the retinal cells of the human eye. The waves of energy differ in their amplitude and in their wavelength characteristics. Energy within a range of wavelengths from about 380 millimicrons (that is 380 ten-millionths of a centimetre from wave peak to wave peak) to about 800 millimicrons stimulate sensations of visible light. At wavelengths shorter than those within this range, the energy is described as invisible ultra-violet light. Certain features of ultra-violet light may constitute a hazard to some workers who are exposed to it. There may be a connection between nutritional deficiencies, ultra-violet radiation and the occurrence of skin ulcers. At wavelengths longer

than those in the range of visible light, the energy is described as infra-red radiation. Infra-red sources of energy take part in the thermal exchanges between man and his working environment.

The intensity of the sensation of light within the range of the visible spectrum is determined in part by the amplitude of the waves of light energy. The hue or colour of the light is related in part to the wavelength of the light energy. Energy wholly at a wavelength of around 400 millimicrons mediates sensations of saturated blueness. Energy waves centred at a wavelength of about 700 millimicrons mediate a sensation of saturated redness. Achromatic or white light is composed of a mixture of wavelengths within the spectrum of visible light waves.

The human eye is remarkably sensitive to differences in the amplitude and wavelength characteristics of the energy that falls upon the eye's retina. The retina is composed of two kinds of receptor cells. It contains cone cells and rod cells. There are some 7 million cone cells in the human retina. In their distribution across the retina, these cells are concentrated towards its centre. This is the part that receives light energy from the centre of man's visual field. It is here that man is most able to see clearly and to differentiate between variations in light and shade, and in colour, because the cone cells are most sensitive to the fine detail of differences in the amplitude and wavelength characteristics of light. These differences provide the basis for man's appreciation of the discrete features of his visual environment. Acuity of vision is greatest when cone cells are stimulated by light waves from the middle area of the visual field. To protect these sensitive cells from over-stimulation in bright colourful environmental conditions, the eye is capable of adjusting the amount of light reaching the retina so that maximally sensitive vision is possible without the hazard of a 'white-out' visual experience that would be produced by the reception at an unprotected retina of very intense stimulation. In conditions of daylight, with a light-adapted eye, the retina's cone cells have the chief 'responsibility' for vision.

In poor lighting conditions and towards the periphery of the visual field, 'responsibility' for vision switches to the rod cells of the retina. There are over 100 million of these cells in the

human retina. Proportionately, they are more frequent in those parts of the retina that receive light waves from the outer areas of man's field of vision. The rod cells are sensitive to differences in the amplitude characteristics of the light waves. They function well at low levels of light energy when the eye becomes dark-adapted to facilitate the maximum use of the reduced light energy available in the environment. Rod cells are insensitive to the wavelength characteristics of light energy so they do not mediate sensations of colour. Loss of colour sensation at low levels of light energy and towards the periphery of the visual field is a consequence of a reduction in the part played by cone cells and an increase in the part played by rod cells in these two circumstances.

In industry, differences in the retinal distribution and functioning of these two types of retinal cells of the human eye have important implications for the siting and display features of visual signals. Visual signals may be used to carry important information to the operator either in the form of instructions for the performance of the task or in the form of warning and danger signals. If these types of visual signals are to be effective transmitters of information, it is necessary for their design and placement to be in accordance with the features of human visual functioning. Visual acuity is less with rod vision than with cone vision so that the loss of the ability to identify small detail in the peripheral areas of vision and in low levels of illumination must be taken into account in environmental visual design. Colour coding of information will be less effective as it becomes mediated by parts of the retina that are less well endowed with cone cells. Visual acuity and colour sensation maps of the human visual field are useful aids to the designer of the visual elements of industrial environments.

II *Measurement of Light*

The intensity of a light source is expressed in terms of the amount of luminous flux it generates. Measurements of the luminous flux are based upon comparisons with the luminous flux produced by the burning at a specified rate of a 'standard

candle' of specified weight. This standard candle is said to produce one candle-power of energy. The light energy radiates in all directions from its source and loses its intensity as it travels through a dense medium such as air, water, glass, etc. The greater the density of the medium through which the light energy travels, the greater is the loss of energy. Density of any medium may be increased, of course, by the suspension in that medium of 'foreign matter'. Thus a humid atmosphere is more dense than one with less vapour in it. A dusty, polluted atmosphere is more dense than a dust-free, clean one. The purest, most translucent, glass window or sky-light is already a formidable barrier to the transmission of light energy. When, as may often happen in some industrial environments, windows or sky-lights have been painted over, left unclean for months, or become dimmed through condensation due to an inadequate ventilation system, their effect on the loss of intensity of light energy is even more marked.

The rate of loss as light energy travels through air is related to the square of the distance travelled. Thus if the distance is doubled, the level of light intensity drops to a fourth. Measures of luminous flux, therefore, must take into account not only the power of the source of light but also the distance that the radiated energy has travelled. A standard unit has been defined that expresses the total amount of energy received on the inner surface of a sphere at a distance of one metre from the burning at its centre of a standard metre-candle. This unit is called the 'lux'. With the same candle burning as its power source, the intensity of the luminous flux at 2 metres distance would be a quarter of a lux, at 3 metres distance a ninth of a lux, and at 4 metres distance a sixteenth of a lux. If the energy source is 100 times greater than a standard candle then the 100 cp (candle-power) source produces 100 lux of luminous flux at one metre distance, 25 lux at two metres distance, about 11 lux at three metres distance and about 6 lux at four metres distance. It will be appreciated, in view of what has been said about some industrial environments, that in some work-shops and offices this rapid loss of light intensity may be grossly exacerbated by the intrusion of dense barriers to its transmission.

In addition to the distance travelled, and the density of the medium through which it travels, as factors serving to reduce light intensity, there is a third reducing factor that in some respects is the most important of all. This is the absorption of light energy by the objects receiving it. In any environment we may be aware of two sources of light. There may be the original, direct source of illumination, and there may be the surfaces of the objects and surroundings in the environment that are seen because they reflect some of the light that falls upon them. The variation in the extent to which objects in our environment reflect the light energy they receive is almost as great as the variety of objects with which our environments are filled. A highly polished surface may reflect something like 90 per cent of the light energy falling upon it. A dull, matt surface may absorb that amount and reflect only about 10 per cent of the light energy it receives. Because our retinal cells can be stimulated only by the light energy that the objects reflect back rather than by the energy they receive, it is necessary to use a further measure to describe the lighting characteristics of the physical environment. This measure is used to express the 'brightness' of objects. The unit of brightness is called the 'lambert'. The lambert is defined as the average brightness of a surface reflecting 100 per cent of 10,000 lux falling upon it. A 'millilambert' expresses the brightness of a surface that reflects 100 per cent of the light energy of 10 lux of luminous flux falling upon it.

The reflectance-absorption properties of the surfaces that comprise environments not only determine brightness factors through their absorption of energy. The vast majority of objects and surfaces also affect the wavelength characteristics of the light energy reflected off them. When white light falls upon some objects, light waves of all except one narrow band of wavelengths may be lost through their absorption. The wavebands that are reflected from the surface of an object are the ones that stimulate the cone cells of the retina. These give rise to a sensation of colour which we interpret as the colour of the object or surface. If the reflected wavelengths are close together in the visual spectrum we identify the colour as being pure, or saturated, or strong. If the wavelengths that are reflected

from the surface of an object on which white light falls are a wider selection from the visual spectrum, we identify the colour as being desaturated or weak. For a given intensity of reflected light, human beings tend to attribute greater brightness to saturated colours than to desaturated ones.

Few objects, walls, floors, ceilings or other surfaces in industrial environments reflect 100 per cent of the intensity and wavelength characteristics of the light that falls upon them. Indeed if such conditions of 100 per cent reflectance did exist and white light illumination were provided, a largely featureless environment would ensue. The changes in brightness of surfaces that differed only in their distance from the light source would probably be too small, in many instances, for one surface to be differentiated visually from another. Such an environment would present many potential hazards to the safety and efficient functioning of workers. Manipulation of objects and the avoidance of obstacles would be extraordinarily difficult. Differences in brightness and hue are the foundations upon which our visual world is built. Without this variety a very bland environment would result.

In fact, the most frequent lighting problems in industry are not that there is too much general illumination but that too much general illumination is lost because of polluted atmospheres and dirty, poorly reflectant surfaces. The main adverse effect of too much light in industry arises in connection with sources of glare. The phenomenon of glare will be discussed later in this chapter.

III *Legislative Recommendations*

In general, the windows, lamp fittings, fluorescent tubes or tungsten lamps and their covers, and many atmospheres in industry are insufficiently clear of pollutants to permit more than a fraction of the light energy to travel from its source to the work-bench. In order that this loss of light energy should not be so great as to impair seriously the safety and efficiency of industrial workers, attention must be paid not only to the siting and power characteristics of light sources but to the

cleanliness of the working environment. This concern has been shown in legislative enactments. For example, in the United Kingdom, the Factories Act of 1961 required in its Chapter 34, Part 1, Paragraph 5 that:

> (1) Effective provision shall be made for securing and maintaining sufficient and suitable lighting, whether natural or artificial, in every part of a factory in which persons are working or passing. . . .

and

> (4) All glazed windows and sky-lights used for the lighting of work-rooms shall, so far as practicable, be kept clean on both inner and outer surfaces and free from obstruction; but this subsection shall not affect the whitewashing or shading of windows and sky-lights for the purpose of mitigating heat or glare.

Similar provisions were made in the Offices, Shops and Railway Premises Act of 1963. Responsibility for ensuring that the requirements of these Acts are met is shared, in the United Kingdom, between local government authorities and Her Majesty's government inspectors.

Recommendations about levels of illumination at specific places of work were made by the British Illuminating Engineering Society in 1968. These range from a recommended level of general illumination of 600 lux at 0·85 metres above the floor for the work areas of shop counters, business and computing machines, tracing-boards and drawing-boards, to a recommended level of general illumination of 100 lux at a similar height above the floor for warehouse loading-bays, restaurants and dining-rooms, staff rest-rooms, cloak-rooms and wash-rooms. A level of general illumination at floor level of 100 lux is recommended for stairways, escalators, corridors and passageways.

Minimum permissible levels of general illumination of either 54 or 75 lux are appropriate for entrance halls, reception areas, cloak-rooms, stairs and escalators, lifts, corridors, warehouse loading-bays and dining-halls. If a special effect of informality or intimacy is desired in dining-rooms, restaurants or rest-

rooms, then the minimum level of general illumination may be reduced to 8·4 lux. However, for the adequate cleaning of these and similar locations, the Illuminating Engineering Society recommends that a minimum level of at least 107·6 lux is necessary. It will be noted that in these recommendations allowance is made for the reduction of light energy as it travels from its source by specifying levels of illumination at, or near to, the actual work-place rather than at, or near to, the light source itself.

IV *Emotional Effects*

Lighting conditions at the place of work may have two kinds of effects upon workers. They may affect his visual efficiency and hence his performance, or his safety and well-being. They may also have more subtle effects that act only indirectly upon the worker's efficiency. Some lighting designers and consultants have emphasised the importance of this latter category of psychological effects of lighting and decoration schemes. Subjective reactions of workers to their visual environment may vary from a 'gloomy, depressing deadening of the mind' associated with an environment of dark, matt colours and low levels of illumination, to a 'cheerful, alert feeling of well-being' associated with a bright, colourful decorative and lighting scheme. These descriptions of some effects that features of the visual environment may promote, have not been studied sufficiently for any general templet to be drawn of the subjective reactions consistently induced by particular colour and illumination combinations. It is true, no doubt, that some workers may express feelings similar to the examples given above. It may be true, too, that industrial working conditions could be classified along a brightness-dullness and a colourful-achromatic continuum. However, at present, it is by no means established that there is a close and consistent relation between man's visual environment at work and his emotional state. Before any definitive statement may be made about the emotional impact on workers of their visual working environments much more research will have to be completed.

Emotional responses to environmental variables have been much neglected as a subject of study. There are, scattered about the literature on man's reactions to his physical environment, a number of intuitive statements and unsupported assertions that such emotional responses do occur. These might serve as a useful source of hypotheses for future research programmes in psychology and allied disciplines. Part of the problem in such research is that of finding a satisfactory way of describing and categorising or quantifying environments in terms of those features that might have an emotional impact upon workers. Even if that problem were solved, however, there would remain an equally difficult task of finding a means of assessing emotional changes in man. Measurement of effects of this kind would be more complex than measurement of effects in terms of performance efficiency. Very few aspects of human behaviour and experience are susceptible to the establishment of causal links with a single environmental variable. In the realm of emotional responses, not only must many features of the visual environment be taken into account, but attention may also have to be given to other environmental influences of a social nature.

At the moment, it is reasonable to assume that most of what we know of our emotional reactions to colour schemes and illumination levels is intuitive rather than based upon any empirical data. Sometimes expert intuition may be effective in promoting lasting improvement in the occupational environment. This is not invariable, however, for sometimes an improvement may be transitory and as much due to the expert being present in the environment as to any recommendations he may make about improving it. Whether it is inadvisable to wait for the production of evidence before encouraging industrialists to attempt to improve the lighting and visual environments of their workers is a question to which there is no ready answer. In respect of workers' emotional reactions to their visual environment all that may be available to an industrialist may be the expressed opinions of expert consultants. Scientific backing for these opinions may be produced sooner rather than later if only because the opinions have been expressed.

V *Performance Effects*

Criteria of performance effects of lighting and visual features of working environments have tended to be related to fault-seeking, speed of recognition of signals, and frequency of errors (omission or commission). Studies by ergonomists have led to guidelines for effective lighting arrangements of visual displays. The variables included comprise levels of general and specific illumination, contrast phenomena, colour coding of signals, and the spatial location of information sources in the worker's visual field. Two main aims are discernible. One has been to seek a definition of the conditions under which maximum visual acuity may occur. The other has been to minimise the likelihood that sources of light and extraneous signals might distract the attention of the worker away from a primary task in which he is engaged.

In day-light vision, maximal visual acuity occurs when light, reflected from objects in the centre of the visual field, stimulates the cone cells of the fovea of the retina. If this maximal visual acuity is given a value of 100 per cent, a loss of visual acuity, as the retinal cells stimulated are further and further away from the fovea, may be expressed in percentage terms. Cells in the retina that lie on a circle at approximately 10° from the fovea are capable of a visual acuity potential, under ideal conditions, of about 20 per cent of the foveal acuity level. More peripheral retinal cells at about 30° to 40° from the fovea are capable of mediating a level of visual acuity that is only 5 or 6 per cent of that possible from foveal cells. Thus, a small detail in man's visual environment that is capable of being seen when it occurs in the centre of the visual field would need to be increased in area by about twenty times if it is to be seen by cells in the more peripheral parts of the retina. This loss of visual acuity with peripheral vision may be compensated for, of course, by turning the head and eyes so that an object comes to stimulate more central areas of the retina. However, in some industrial tasks the industrial designer may be concerned with a situation in which the worker is required to concentrate his visual attention in the centre of his visual field whilst keeping a 'weather

eye' on possible visual signals from more peripheral parts. In these circumstances, peripheral signals must be designed with due attention being paid to the loss of visual acuity associated with stimulation of peripheral parts of the retina. Size and location of all types of visual signals are important conditions of efficient performance of many tasks and in the presentation of danger and warning signals.

Within the central 30° of the worker's field of vision, maximum illumination and brightness should be obtained. For fine work, visual acuity may be enhanced and visual errors of misidentification may be reduced by providing levels of illumination of 750 lux to 1,500 lux. These levels are recommended for the performance of work on radio and telephonic equipment, the assembly of typewriters and office machinery and the manipulation of fine instruments. The most appropriate level of illumination for a particular task will depend upon the nature of the materials being inspected or handled. Care must be taken in the provision of high levels of direct illumination that the location of the light source does not itself present a hazard to efficient performance. If the job requires identifying and manipulating objects with high reflectance values, the dazzle of reflected light from the objects may severely reduce the worker's visual performance unless the siting and form of the source of illumination has been chosen deliberately to prevent this happening. Similar deterioration in performance may occur if the source of light is so close to the worker's line of vision when he is attending to his task that the risk of distraction of attention is high.

VI *Glare*

Glare phenomena reduce the efficiency of performance and may produce unpleasant subjective effects. They are contrast phenomena in an exaggerated form. Contrast effects are found when two adjacent areas of the visual field have different brightness values. Some degree of contrast is necessary, of course, for the differentiation of features of the visual environment. The human eye emphasises differences in the brightness of adjacent areas

of the visual field by 'seeing' the bright area as brighter and the dark area as darker. When the contrast between the two adjacent areas is great, the tendency to see the dark area as darker sometimes means that objects that could have been seen quite clearly when not close to a bright area fail to be seen in the contrast context. In general, the loss of vision for darker areas becomes greater as the brighter area is larger, brighter, and closer to the man's line of vision. The interference with visual efficiency from a brighter source of light is the substance of glare effects.

When the interference from glare sources causes a loss of visibility of objects in the central, less bright, field of vision of about 40 per cent the presence of the glare source is experienced by workers as 'distracting'. If the visual loss rises to about 50 per cent, feelings of distraction give way to annoyance. It is probably at this level of interference that steps will be taken to remove or reduce the glare. If its removal or reduction has not been completed and a glare source causes a loss of visual efficiency of about 70 to 80 per cent, the worker will experience feelings of strain leading to visual and mental fatigue.

These are general findings for 'average' workers. Although the literature has little to say about individual differences between people in their reactions to stress from glare, it is possible that there is a wide range of sensitivity to glare effects among worker populations. This differential sensitivity may not only occur in the *sensation* of light evoked by a glare source but, for a given perceptual sensitivity, there may be differences between people in their *tolerance* of the glare. Further, there may be important differences in the *reactions* to glare stress beyond individual tolerance limits, such that some people may be prone to remove the source of glare, or to abandon the work that the glare is interfering with, or to try to continue the work in the presence of the glare and produce psychological strains within themselves. Individual differences in sensitivity, tolerance and reactivity under conditions of environmental stress have received relatively little attention in the past. At a superficial level of analysis, it seems reasonable to assume that a worker who is distracted from a task that is important to him, that is being

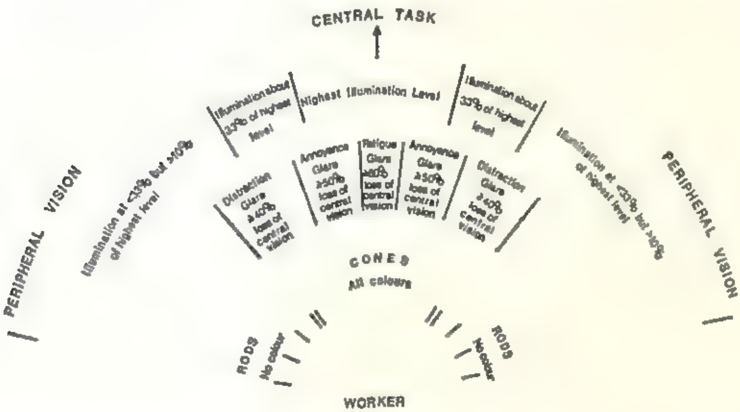
performed under conditions of fast pacing or supervisory pressure, or in which one minor error may entail long, arduous retracing of previously completed steps, will tend to react more violently than a worker less committed to the task. The significant variables determining stress reactions are not yet fully explored, however, and it is difficult to draw implications pertaining to particular occupational conditions from general statements about a worker's involvement in the task he has to perform under environmental stress. Except, perhaps, in research into the anthropometric aspects of industrial design that will be discussed in Chapter 4, most emphasis of investigations into industrial conditions has been placed on assessing the reactions of the 'average man' or 'standard man', rather than on attempts to discover differences between men in their susceptibility to various aspects of their physical environments at work.

Glare effects are potentially most damaging if the illumination of the central task area is being provided by a light source within about 10° of a worker's line of vision when attending to his task. The effects may be exacerbated in the case of a task requiring the manipulation or identification of objects against a highly reflectant background surface. Similar problems may arise if the task objects themselves have highly reflectant surfaces. The placement of any brightly coloured, high contrast or high reflectance objects or surfaces in those parts of the working environment that excite retinal cells adjacent to the cells excited by the task itself may result in marked deterioration in the efficiency with which the task is performed. In general, therefore, glare effects are greatest when the source of glare is closest to the line of vision between the eye and the central task and when the contrast that promotes the potential glare phenomena is most marked.

VII *Adequate Lighting*

To ensure efficient performance of visual tasks it is necessary to achieve adequate lighting conditions in the central part of the worker's visual field that the task occupies. Some examples of recommended illumination levels have already been given earlier

in this chapter. Provided that sources of glare have been removed, further recommendations may be made concerning the desirable levels of contrast between the brighter central and less bright peripheral areas of the worker's visual field. It has been suggested, for instance, that if the central 30° of the visual field is taken as the task area, this should have the highest level of illumination to make it the brightest area of the total visual field. A ratio of brightness between this area and the immediately surrounding area from 30° to 60° should be not more than about three to one. A similar ratio should obtain between the area within the 30° to 60° circles and the most extreme areas of the visual field. This ensures a gradual reduction in brightness from most central to most peripheral areas of the visual field so that the outermost areas are kept at less than 100 per cent but more than about 10 per cent of the level of brightness of the central region.



Within the well illuminated central region attention must be paid to the provision of adequate figure-ground separation if performance of tasks with a major visual element is to be efficient. The identification of task components against their background may be assisted by the judicious use of colour contrasts. Some wavelengths of light have complementary relationships with others, so that the presence of one in simultaneous or

successive proximity to another, highlights the saturation of each. Complementary colours may be more readily distinguished from each other than other pairings. This phenomenon may be easily observed when a piece of red material, reflecting light waves of about 660 millimicrons, is placed against a background of either blue-green, reflecting light waves at about 495 millimicrons, or against a background of yellow, reflecting light wavelengths of about 585 millimicrons. The saturation or redness of the patch will appear to be much more intense when viewed against the former background than when viewed against the latter. Similar effects may be found with other colour combinations. Blue at about 485 millimicrons has a complementary pairing with yellow at about 585 millimicrons. Where such colour codings are used to facilitate task-background differentiations care must be taken to ensure that the workers who will be employed on the task do not suffer from a form of colour blindness that will neutralise the contrast phenomena.

Another use of colour coding has been given increasing use in industrial design. This is related to the design of displays for the presentation of complex information or the indication of sequences of actions required in the performance of complex tasks. Improvements have been found in reducing errors and the time taken to perform a succession of actions or to monitor a series of displays when the task has been visually structured to assist the worker. Older task design, based on engineering principles, often took no account of the task presentation to the worker so that much waste of time could be caused by the operator searching for each successive step in a sequence. Errors in reading displays or in operating controls could result from inappropriate task design. Although it is possible that years of over-learning or the adoption of mnemonic devices could assist the worker during normal operations, these may be of little assistance during emergencies and during trouble-shooting activity when the worker is unaware of the principles of the underlying process.

In several modern industries, particularly electronics and those in which automation of processes has reduced the amount of direct contact between the worker and the process he is

required to monitor, errors of operation have become so costly that industrialists have encouraged research into the demands the task makes on the operator. When a worker is faced with the problem of dealing with 'too much' information, the load on his attention may be reduced by grouping some of the bits of information into larger, interconnected, units. The load may be reduced, too, by the spatial arrangement of a set of displays that must be attended to in a particular sequence. In research into task design a prominent feature of investigation has been the way in which component parts of tasks that have a temporal or logical contiguity may be coded by the use of colour. Not only may colour coding be used to group interconnected parts of a display of information, but it can also assist the worker in the choice of appropriate control knobs that have been placed in related locations and given a similar colour code. As industry becomes more sophisticated technologically, workers may be required to act more often as controllers of processes that are no longer directly handled or observed by them. This type of change in the nature of industrial jobs has far-reaching implications for the planning and testing of new ways of organising display and control systems so that they become more appropriate to the capacities and limitations of the workers who have to operate them.

VIII *Protective Visors*

In this chapter so far, the lighting environment of men at work has been considered from the point of view of its effects upon visual acuity, on figure-ground differentiation, on subjective emotional experiences and on the discomfort, distraction and disability arising from glare. Some men at work are subject to an aspect of their visual environment that is potentially more hazardous to their well-being. In some industrial environments, there may be extremely intense sources of light energy, such as furnaces, arc lamps and spot-welders, that could cause severe and permanent damage to any retinal cells directly stimulated. Because of this risk in some industrial contexts, as well as a risk of foreign matter being blown into unprotected eyes, consider-

able effort has been devoted to the design of protective visors. The aim of the visors is usually either to reduce the general intensity level of the light energy entering the eye from the environment or to alter its wavelength characteristics. Some of the visors appear to be remarkably effective protective devices when assessed against physical or physiological criteria. They cannot be effective, however, if they are not worn correctly by workers in the risk-prone environmental conditions. This means that it is not only necessary for research into design features of protective visors to be effective but also that it is equally necessary for the scientist to plan a successful propaganda exercise to promote acceptance and habitual use of a newly invented protective device by those whom it is intended to protect. Sometimes, a problem that has been taken from industry into a laboratory has had a 'solution' produced in the laboratory which failed to be subsequently transposed back into industry. In general, those engaged in the design of devices to protect workers from the more extreme industrial hazards have paid greater attention to the needs and attitudes of their 'customers' – the workers at risk – than have investigators engaged in the redesign of less hazardous aspects of industrial environments.

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CHAPTER 3

Noise

Noise in the environment of man at work is studied usually as a source of hazard to the worker who may suffer its effects in feelings of annoyance or pain, in distraction from efficient performance, or in damage to his hearing. Noise is also, however, a source of information to the worker. It may provide a useful and necessary medium of communication, social exchange, instruction, or a variety of warning and alarm signals. The communication aspect of noise in the environment of men at work has been given less attention than has its hazardous aspect. This is perhaps in part due to a nomenclature that has evolved in which auditory stimuli are called 'noise' only when they are regarded as inimical to the worker because they are redundant, annoying or meaningless. If auditory stimuli are regarded as useful, acceptable, or meaningful to the worker they tend to be called 'sound', and to be thought of as less of a problem for investigation. For the purpose of the present discussion, it is proposed to refer to all auditory stimuli as noise, but without the implication that noise is inevitably or necessarily 'unwanted', 'hazardous', or to be removed from the workers' environment.

Categories of noise at the place of work are many and varied. Noise may be listened to for its meaning. Meaning may be communicated by speech, or by signals for starting or finishing work, or by changes in the noise characteristics of machinery which indicate to the skilled ear that, say, a crank-shaft is misaligned, a bearing needs lubricating, or a tappet needs adjustment. Noise may be irrelevant and intrusive. If it enters a worker's consciousness, it may be heard rather than listened to. This un-

wanted noise may be continuous throughout the working day, or it may be intermittently present for seconds, minutes or hours, at random or regular intervals, through the day. Noise lasting for more than a few seconds may maintain a steady level of intensity and a uniform pitch, or it may vary systematically or randomly in its characteristics. Impulse noise may occur from time to time at high levels of intensity either in single impacts or in tens or hundreds of single impacts grouped closely together in time.

I *The Noise Stimulus*

Whatever 'receptive category' that auditory stimuli belong to, their physical attributes may be described in common terms. Noise impinges upon man through the arrival at the tympanic membrane of the ear of a sequence of air pressure changes due to successive waves of compression and expansion of the medium through which the waves travel. These waves originate at the noise source and spread in all directions at a rate through air of approximately 344 metres per second. As they spread from their source, the amplitude of their compression-expansion is reduced as a function of the square of the distance travelled. Thus if location B is twice as far from the noise source as location A, the amplitude of the noise at B is only a quarter of what it was at location A. The degree of compression-expansion of the medium and the frequency with which the compression-expansion cycle occurs are the basic components of the physical characteristics of auditory stimuli.

The amplitude of the noise stimulus is reflected in the maximum degree of compression of the air from which sound pressure values are measured, in Newtons per square metre. The total integrated energy transmitted in a wave of compression and expansion may also be measured as a sound energy value. An increase in sound pressure is associated with an increase in sound energy. The latter increases as the square of the former. A three-fold increase in sound pressure is like a nine-fold increase in sound energy.

The frequency of the cycle of compression-expansion of the

medium defines the other physical attribute of auditory stimuli. This is the frequency itself per unit time and is measured in 'Hertz' (Hz). One Hertz is equal to one cycle per second. Another way of describing the frequency characteristics of auditory stimuli is to use the length of the wave of compression-expansion in metres. The shorter the wavelength in metres is, the greater is the number of Hertz. Most auditory stimuli that occur outside audiometric laboratories are composed of combinations of various sound pressure levels and various frequencies. It is rare to find a pure tone, single frequency, stimulus at a constant sound pressure level anywhere in nature or in the man-made world.

II *Human Hearing*

Human hearing is possible, at certain frequencies, over a range of sound pressure levels from about 0·00002 Newtons per square metre to about 50 Newtons per square metre. The greater of these two values is approximately two and a half million times higher than the smaller value. Assessment of audition at high pressure levels is difficult to make because human experience of such stimuli begins to change from that of hearing to that of auditory discomfort, leading to irritation and pain as pressure levels increase. Considerable differences between people in their tolerance of this discomfort or pain have been found. Perception of the intensity of an auditory stimulus is closely linked to the pressure level of the noise, although the frequency characteristics of the stimulus also play a part in determining the perceived intensity level.

We can hear noise, at certain intensities, over a range of frequencies from about 15 Hertz, or a wavelength of about 22 metres, to about 20,000 Hertz or a wavelength of about 0·017 metres. Methods of assessing hearing at very low frequencies, where the stimulus shades into vibration, are fraught with many difficulties. Within these frequency limits, the human ear is particularly sensitive to auditory stimuli that fall within a frequency range of 1,000 Hertz to 4,000 Hertz. As the frequency characteristics of stimuli for noise move outside this range,

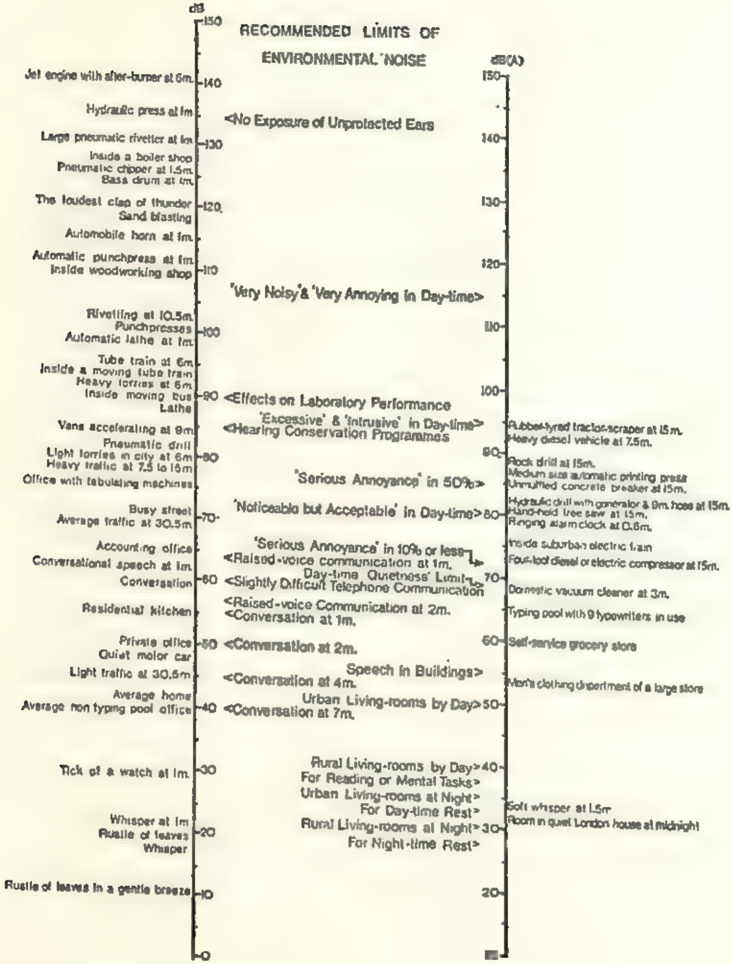
sensitivity to low levels of intensity becomes progressively less. Perception of the pitch of noise is most closely related to the frequency characteristics of the stimulus. High frequency stimuli are perceived as having a high pitch and low frequency stimuli are perceived as having a low pitch.

The loudness of a noise is not usually described directly in terms of the physical properties of the stimulus. A logarithmic scale of relative loudness has been adopted that takes as its zero point a pressure level of 0·00002 Newtons per square metre. All measurements of the intensity of auditory stimuli that are based upon pressure levels are made in relation to this 'base-line' or 'reference' pressure level. The original scale of intensity expressed, for each stimulus, the logarithm of the ratio of its *energy* level to the reference *energy* level. As a ratio of energy levels is the square of a ratio of pressure levels, a logarithmic transformation and a further step are necessary when using pressure levels. In this case, a ratio of pressure levels is converted into its logarithm and then multiplied by two. The same result may be obtained by taking the ratio of the pressure level of the noise stimulus and the base-line pressure level of 0·00002 Newtons per square metre, squaring the ratio and converting it into a logarithm.

An example may serve to illustrate the procedure. If you were to read this page aloud to a friend sitting perhaps a metre or so away from you, and your friend happened to have a pressure meter available, it could be pointed at you and provide a measurement of the waves of compression-expansion that your speaking voice is producing. The frequency characteristics of those waves determine the kinds of sounds that you will be heard to be making. The degree of compression-expansion of the air which you cause corresponds to the amplitude of the stimulus you are producing. As the waves of compression-expansion progress away from your vocal chords and mouth, towards your friend, they will be losing their amplitude. By the time they reach the pressure meter of your friend, they may be producing a maximum degree of compression of the air of about 0·011 Newtons per square metre. If your friend happens to have a pencil and note-pad, he could easily calculate that the sound of

your voice *as it reaches the meter* has a pressure level that is some 550 times greater than the base-line pressure value of 0·00002 Newtons per square metre. This pressure ratio of 550 may be readily converted into a measure of intensity provided that there are logarithmic tables within reach. Your friend may convert the ratio into logarithms (log 550 = 2·7404) and then multiply the logarithm by two (2·7404×2 = 5·4808). Alternatively, your friend may find the square of the pressure ratio (550×550 = 302,500) and then convert this into its logarithm (log 302,500 = 5·4807). In both cases a similar value is reached. The logarithmic scale of noise intensity is based on units called Bels. It is a convention to use a tenth of a Bel, decibel (dB), as a unit. Your voice as it reaches your friend, therefore, may be described as having an intensity of approximately 55 decibels (5·48 Bels × 10).

Although some of the research into the effects of noise has employed stimuli of the pure tone variety, it must be re-emphasised that it is very unusual to find pure tone noise anywhere else. Most natural and man-made noises in industry and elsewhere consist of a 'complex' of frequencies and intensities. It is usual, when a noise stimulus is to be measured, to analyse it into specified ranges (bands) of frequency and assess the average intensity level of the noise within each of these bands. The conversion from pressure levels into decibels is an adequate assessment of noise intensity provided that the range of frequencies contained in the stimulus is not very different from the range of maximum auditory sensitivity in man. Outside this range, however, misleading indications of intensity may arise from the straightforward use of the formula for conversion to decibels. In reports of research into noise effects on human performance and well-being decibel values are habitually expressed 'with reference to the usual arbitrary zero level of 0·00002 Newtons per square metre'. The threshold of human hearing is not very far above 0·00002 Newtons per square metre for stimuli within a range of frequencies from about 1,000 Hertz to about 4,000 Hertz. Above and below this range, however, the minimum pressure level capable of generating a sensation of hearing rises rapidly. At about 20,000 Hertz, for instance, the


RECOMMENDED LIMITS OF ENVIRONMENTAL NOISE
dB
dB(A)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Jet engine with after-burner at 6m.
Hydraulic press at 1m.
Large pneumatic rivetter at 1m.
Inside a boiler shop
Pneumatic chipper at 1.5m.
Bass drum at 1m.
The loudest clap of thunder
Sand blasting
Automobile horn at 1m.
Automatic punchpress at 1m.
Inside woodworking shop
Rivetting at 10.5m.
Punchpresses
Automatic lathe at 1m.
Tube train at 6m.
Inside a moving tube train
Heavy lorries at 6m.
Inside moving bus
Lathe
Vans accelerating at 9m.
Pneumatic drill
Light lorries in city at 6m.
Heavy traffic at 7.5 to 15m.
Office with tabulating machines
Busy street
Average traffic at 30.5m.
Accounting office
Conversational speech at 1m.
Conversation
Residential kitchen
Private office
Quiet motor car
Light traffic at 30.5m.
Average home
Average non typing pool office
Tick of a watch at 1m.
Whisper at 1m.
Rustle of leaves
Whisper
Rustle of leaves in a gentle breeze
<No Exposure of Unprotected Ears
'Very Noisy' & 'Very Annoying in Day-time'>
<Effects on Laboratory Performance
'Excessive' & 'Intrusive' in Day-time>
<Hearing Conservation Programmes
'Serious Annoyance' in 50%>
'Noticeable but Acceptable' in Day-time>
'Serious Annoyance' in 10% or less
<Raised-voice communication at 1m.
Day-time 'Quietness' Limit
<Slightly Difficult Telephone Communication
<Raised-voice Communication at 2m.
<Conversation at 1m.
<Conversation at 2m.
Speech in Buildings>
<Conversation at 4m.
Urban Living-rooms by Day>
<Conversation at 7m.
Rural Living-rooms by Day>
For Reading or Mental Tasks>
Urban Living-rooms at Night>
For Day-time Rest>
Rural Living-rooms at Night>
For Night-time Rest>
Rubber-tyred tractor-scraper at 15m.
Heavy diesel vehicle at 7.5m.
Rock drill at 15m.
Medium size automatic printing press
Unmuffled concrete breaker at 15m.
Hydraulic drill with generator & 9m. hose at 15m.
Hand-held tree saw at 15m.
Ringing alarm clock at 0.6m.
Inside suburban electric train
Four-foot diesel or electric compressor at 15m.
Domestic vacuum cleaner at 3m.
Typing pool with 9 typewriters in use
Self-service grocery store
Men's clothing department of a large store
Soft whisper at 1.5m
Room in quiet London house at midnight

minimum pressure level for hearing is also the pressure level at which pain in the inner ear is felt. A given pressure level is thus much less above a threshold of hearing in those frequency ranges in which the ear is less sensitive than when within the range of frequencies at which it is most sensitive. Thus a similar pressure level may be felt as more intense or less intense depending upon the frequency band within which it occurs.

In order to take account of the influence of frequency characteristics on the noise intensity of pressure levels, several modifications of the decibel scale have been suggested that give a differential weighting to the intensities of noise stimuli in various frequency bands. One of the most widely used in industry is the modification 'A' of the decibel scale. The degree of difference between a decibel rating of a noisy environment and a rating on the 'A' modification depends upon the frequency composition of the noise. The former rating would be expressed in terms of so many dB and the latter in terms of so many dB(A). The diagram shown on page 54 indicates some recommended limits of intensity expressed on either the dB scale or the dB(A) scale. Some 'representative' noise levels are shown in terms of one or other of the two scales. Direct transposition between the two scales of any particular noise stimulus is not possible unless details of its frequency characteristics are known. Other modifications of the original decibel scale such as those giving units of dB(B), dB(C) or dB(D) are used in specialised aspects of noise assessment.

III *Noise in Industry*

Research into the noise environment of men at work has reflected the interests of several different approaches to the study of the interaction between men at work and their physical environment. Occupational hygienists have conducted surveys of the degree of noise hazard in various occupations. They have also described the results of surveys into the incidence of hearing loss in various groups of workers, but they have not always correlated these two sets of observations. A frustrating feature of any attempt to summarise research on this topic, in order to

suggest improvements in a specific industrial situation, is the lack of uniformity in the types of data that are available.

Some reports provide only average intensity levels, without any indication of the frequency spectra of the noise. Sometimes noise-hazard occupations have been drawn together into a catalogue arranged in terms of the products manufactured rather than in terms of the details of the noise present. Studies of the incidence and degree of hearing loss for signals in one frequency band have been made without any note of the general nature of the noise environments that may have contributed to the hearing loss. On some occasions, reports give the percentage of workers in various occupational groups in whom some degree of hearing loss has been detected, without any indication of their age, duration of exposure to noise, characteristics of the noise, or the degree and type of hearing loss suffered. The investigator called upon to give advice on the noise hazard to which a particular group of workers might be subjected faces a difficult task.

IV *Laboratory Performance Effects*

Laboratory investigation of the effects of noise on efficiency in performance has been pursued both by ergonomists and by experimental psychologists. In these studies, the noise stimuli have often taken the form of 'white noise' in which there are no outstanding peak intensities at selected frequencies and a *shshsh* kind of noise is produced. Performance has been assessed on a variety of laboratory tasks that may not have adequately simulated the kind of jobs performed by workers. Conditions of continuous and intermittent noise at various levels of intensity have been studied for their effects upon task performance. Other laboratory research, mostly by audiologists and experimental psychologists has explored the capacities and limitations of the human auditory system in respect of its utilisation of auditory signals. In these studies, the noise stimuli have sometimes been pure tones or combinations of pure tones of known intensities. Data from this kind of investigation have been examined for their relevance to, their support or contradiction of, theories of hearing.

Conclusions drawn from laboratory research, that significant effects on the efficiency of performance are unlikely below noise intensity levels of about 90 dB to 95 dB, have to be extrapolated with some caution to conditions and effects on the factory floor. Not only may the personnel and the tasks studied in the laboratory be unrepresentative of the factory context but the noise characteristics may be quite different too. It is quite rare to find industrial conditions in which the noise impinging upon the workers is similar to the white noise or pure tone combinations used in the laboratory. It is probably more likely that the noise to which workers may be subjected will have peak intensities at particular frequencies which may change systematically or randomly over time during the working day. For an extrapolation to be successful from laboratory to industry, the simulation of *all* the significant features of the latter in the former is necessary. Part of the aim of laboratory research should be not merely to establish statistically significant effects upon the performance of highly sensitive, specially designed, tasks that may require the maintenance of a high level of sustained attention, but to establish which features of noise environments are responsible for which effects. It is also desirable to know whether the effects of significant noise features are modified by the total noise environmental context within which they occur. A laboratory-to-industry matching process is an essential prerequisite for a legitimate transposition of problems or solutions from one to the other. Indeed it might be argued that the usefulness of attempts to achieve successful communication between laboratory and work-shop is dependent directly upon comparability between the two situations. Unless this comparability has been reached, effects found in the laboratory may be absent, present but different, or similar but of greater or lesser severity, in an industrial context. In dealing with the effects of noise on men at work, attention needs to be paid to the tasks the workers perform, their total noise experience, past and present, and their expectations and attitudes.

The results of the studies of the effects of noise on man in laboratories may be translated only with diffidence to industrial contexts in which there is only that source of hazard. Con-

siderable caution is required in the translation of those laboratory results to industrial contexts in which workers may experience a combination of noise, gloom or glare, smell, draughts, humid atmospheres and toxic fumes.

Despite these difficulties, however, the investigator may often be required to apply his limited knowledge to the solution of an industrial problem. He knows that, in the laboratory, sustained noise at 95 dB and above may cause momentary lapses of attention after thirty minutes or more, and that occasional noise at lower levels introduced during the performance of a boring, long-term, vigilance task may produce a temporary improvement in efficiency. But he may be uncertain about such effects being present in environments outside the laboratory where noise may be only one of several hazards. No one will thank the scientist who refuses to budge from the position that insufficient similarities exist between laboratory and industry for any recommendations to be made about the improvement of the noise environments of men at work.

V *Hearing Loss with Age*

An indication has already been given that investigations of the hearing of young men have suggested that the threshold of hearing varies with the frequency of auditory signals presented as pure tones. Although a level of 0 dB is taken as the mean threshold of hearing, in fact an intensity of about 69 dB, relative to the usual arbitrary zero of 0·00002 Newtons per square metre, is required for a signal to be heard at a pure tone frequency of approximately 50 Hertz. With a pure tone signal of approximately 10,000 Hertz the intensity of about 31 dB, relative to the usual arbitrary zero of 0·00002 Newtons per square metre, is necessary for hearing to occur.

The importance of frequency in the determination of hearing thresholds for young men features equally in the description of the degrees of hearing loss experienced by older men. There is a general tendency for auditory sensitivity to decrease with age and for the rate of hearing loss to become more marked with advancing years. This condition is called 'presbycusis'. Hearing

loss at the low frequency end of the noise spectrum appears to be minimal. From about 300 Hertz upwards, however, hearing loss becomes more marked with age and with higher frequency levels. When the hearing thresholds of young men are studied it is found that, on average, they remain fairly constant over a range of frequencies from about 125 Hertz to about 8,000 Hertz. Men in their middle age, however, require only slightly higher intensity levels (about 5 dB or less) for them to hear signals at 125 Hertz to 1,000 Hertz, but increases in intensity of approximately 10 dB, 15 dB, and 25 dB are required if they are to hear signals at frequencies of about 2,000 Hertz, 4,000 Hertz, and 8,000 Hertz respectively. For retired people and oldest men at work, a greater increase in intensity levels is necessary. At frequencies up to about 500 Hertz signals must be more intense by approximately 10 dB, at 1,000 Hertz by about 15 dB, at 2,000 Hertz by about 20 dB, at 4,000 Hertz by about 30 dB, and at 8,000 Hertz by about 40 dB or more. In some laboratories, it is not unknown for scientists and technicians to perform secret explorations of their ability to hear pure tone signals at various frequencies to judge whether they are growing old at a rate that is faster or slower than their advancing chronological years.

The values of hearing loss that have been illustrated here fail to do justice to the great variation that occurs between people in the extent to which they display presbycusis over any given period of years. Some of this variability, but not all of it, may be attributed to hearing loss associated with exposure over long periods of time to high levels of occupational noise. Even among young workers there may be many temporary shifts of between 20 dB and 30 dB in hearing thresholds due to exposure to industrial noise. In general terms, the greater the intensity and duration of noise exposure at work, the greater the total hearing loss. The question of the origin of wide individual differences in susceptibility to general hearing loss, and hearing loss at particular frequencies, is one that has still to be explored. What is needed is a thorough, systematic and comprehensive investigation of the changes in hearing of large samples of the adult population *and* the environments in which they have been exposed to noise.

Whatever its origin, however, hearing loss that takes place in the range in which conversational speech occurs, from about 300 Hertz to 4,000 Hertz, is particularly important for the well-being and efficiency of men at work. Deterioration in hearing at this range has important implications for the design of training programmes for middle-aged and older workers in industry. This factor, taken with deterioration in the efficiency of visual functioning, calls for expertise on the part of training officers in those industries in which there is a widespread need for middle-aged workers to adapt to the demands of redeployment and changes in the technological sophistication of manufacturing processes.

VI *Signal Clarity*

Face to face verbal communication takes place usually at an intensity level of about 60 dB. Difficulty in verbal communication is found when noise signals forming part of human speech are 'masked' by the intrusion of extraneous noise of similar, or higher, intensity at similar, or lower, frequencies. If the lower frequencies of speech are obliterated, either through hearing loss in this part of the frequency spectrum or through interference from other noise sources, verbal communication becomes less intelligible than if higher frequencies are eliminated from hearing. An extraneous noise, in the speech frequency range, of about 50 dB to 55 dB, barely permits a telephone conversation to take place, or face to face communication to be conducted, without undue difficulty, at a distance of about one metre. At higher levels of intrusive noise, or at a similar level but with participants in a conversation being further apart, verbal communication becomes more difficult.

For any noise signal to be perceived against a background of unwanted noise, the signal must be of a higher intensity. For verbal communication, it is necessary, in general, for the signal intensity to be about 10 per cent louder, or more, than the background noise level. Other signals will be differentiated from background noise, of similar frequency characteristics, only when they are louder by at least 10 per cent. Much larger differences in intensities of signals and background noises must

be attained if the signals are warning or alarm devices. Intermittent, pulsating, frequency-changing, alarm signals are more likely to be heard against a continuous background noise than are constant alarm signals. Some attention must be paid in the design of alarm signals to ensure that a startle response is not produced in the worker. If the alarm is to indicate that the worker's machine must be shut down quickly, a signal that is too startling may induce in the operative an inadvertent switching of the wrong controls in wrong directions unless the machinery has been properly designed in accordance with the kind of expectation criteria that are discussed in the next chapter. This is the realm of industrial design in which the lay-out of control panels and the planning of control operations – especially those concerned with the emergency responses required of operators – is important for industrial safety. Operations that conform to over-learned expectations and responses in particular industrial populations are more likely to be carried out correctly in an emergency situation than are operations that require conscious attention.

VII *Emotional Responses*

An important aspect of the expression of general relations between signal noise and background noise in the determination of signal clarity is the question of the extent to which the signal may be meaningful to the worker. If the signal is significant to the listener, in that he is seeking it, it will be more readily discriminated from less meaningful background noise. It has been found occasionally, when workers have been subjected to a combination of environmental stresses, that meaning may be attributed to random noise in the environment. When this happens, intrusive background noises may become more distracting to the worker's performance than had been expected by the investigator.

A worker who has his attention distracted from a task on which he wishes to concentrate, or who finds that he has to shout in order to be heard by a colleague, or who has to break off his speech in mid-sentence because he 'cannot hear himself

think', may become annoyed about the intrusiveness of the disrupting noise. How annoyed he will feel about the intrusion, and how ready he will be to take remedial action against it, will depend upon a number of complex factors in himself and in the work situation he inhabits. Because of this complexity, it has proved difficult to give any quantitative definition of the environmental circumstances that could be regarded as a 'threshold for action'. It is true that verbal responses to noise have been elicited in terms of a graded evaluation ranging from 'acceptable' to 'extremely annoying'. It is also true that, in surveys of the effects of industrial, motorway, or aircraft noise, attempts may be made to assess tolerance in terms of the number of claims for compensation or the number of movements of households out of the noisy environment. On the whole, however, it appears that for any given physical degree of noise stress, some people will react adversely and some will not, and little is known about the causes of such variety of responses.

Aircraft noise at less than about 72 dB(A) has been found to produce ratings of 'serious annoyance' in only about 10 per cent of those members of the public who were exposed to it. About half of those exposed to aircraft noise levels of about 85 dB(A) described their reaction as 'seriously annoyed'. Any attempts to draw together the results of a variety of surveys of this type must be aware of the danger of over-simplifying the complex interaction between man and his noise environment. With this in mind, it may be noted that, *on the average*, aircraft or vehicle noise is judged in day-time to be 'quiet' at about 70 dB(A) or less; 'noticeable but acceptable' to about 80 dB(A); 'excessively noisy and intrusive' from about 95 dB(A) to about 100 dB(A); and, in respect of aircraft noise, to be 'very noisy and very annoying' at about 115 dB(A). At night-time, when background noise tends to be less and people's expectations of quiet conditions are greater, the noise levels given for each of the categories of response in day-time conditions must be considerably reduced.

VIII *Effects on Performance*

Noise effects on the performance of workers appear to be either negligible, beneficial or deleterious. Intensity levels of 90 dB or less seem to be fairly innocuous so far as performance efficiency is concerned. For workers engaged in tasks that demand little activity but constant awareness over long periods of time, the sporadic introduction of noise may induce an alertness. Noise that distracts from tasks that require sustained close concentration on detail may produce a loss of efficiency due to momentary lapses of attention. In many conditions, however, noise levels appear to produce little effect on the efficiency of performance.

One of the problems that has been met, in assessing the effects of noise on non-auditory tasks, has been that of deciding to what extent there has been a particular contribution of noise among several stresses in the immediate environment. The previous experience of workers in terms of a familiarity with the noise, or adaptation to it, may be an important variable in determining their reaction. The attitude of the workers to the job they are doing, and their relationship with those they judge to be responsible for the presence of noise in their working environment, may serve to complicate any equation between noise environments and efficiency.

IX *Occupational Hearing Loss*

A clear indication of the effects of exposure to noise at work emerges from a consideration of the problem of occupational hearing loss. It has been suggested already that the natural decline in hearing with age (presbycusis) may be exacerbated by exposure to high levels of industrial noise. It appears that there is a relation between the frequency band of industrial noise and the frequency band in which occupational hearing loss is most marked. The frequency spectrum of noise may be divided into octaves. These are frequency ranges in which the highest frequency in the octave range is twice that of the lowest frequency. Thus a range from 90 Hertz to 180 Hertz is one

octave and a range from 2,800 Hertz to 5,600 Hertz is another octave. Occupational hearing loss appears to occur at frequencies that are about half an octave higher than the frequency of the occupational noise to which the worker has been exposed. Loss of hearing may be temporary, with recovery taking place over a period of minutes, hours or days, or it may be permanent and irrecoverable.

Hearing appears to be most vulnerable to loss within the range of 4,000 Hertz to 5,000 Hertz. With continuous exposure to high noise levels, loss in this range becomes greater, and loss at adjacent frequencies becomes evident. The worker may be unaware of the gradual impairment of his hearing until there has been a marked shift in his hearing threshold at speech frequencies of 3,000 Hertz or less. When these losses occur, the worker begins to find increasing difficulty in understanding the speech of his fellow-workers.

The extent and degree of occupational deafness has been plotted amongst a wide variety of workers who are subjected to noise levels of 80 dB to 90 dB and above. Special attention has been paid to discovering the extent of hearing loss at particular frequencies in workers, employed in high noise risk jobs, such as boilermakers, riveters, rolling-mill operatives and drop-forge operatives. It is possible that if a comprehensive survey were to be made of many other occupational environments and the workers in them, there may be found considerably more industrial situations inducing hearing losses than those industries traditionally regarded as noisy.

X *Protection against Noise*

Some governments have attempted to legislate to control noise levels in industrial and civilian environments, and to provide compensation schemes for those who suffer hearing loss. Legislation has not been easy, however, partly because of the difficulty of identifying the gradual, insidious progress of occupational hearing loss. In the United Kingdom there is no specific legislation, apart from the Public Nuisance Law, to control or compensate for exposure to industrial noise. A sub-Committee on

noise of the Industrial Health Advisory Committee of the Department of Employment produced a code of practice in 1971. The code contains the following recommendations:

Section 1: Scope of the code

1:1:1 This code of practice applies to all persons employed in industry who are exposed to noise.

1:1:2 The code sets out recommended limits to noise exposure. It should be noted that, on account of the large inherent variations of susceptibility between individuals, these limitations are not in themselves guaranteed to remove all risk of noise-induced hearing loss.

Section 4: Limits

4:1:1 The limits set out in this section should be regarded as maximum acceptable levels and not as desirable levels. Where it is reasonably practicable to do so it is desirable for the sound to be reduced to lower levels.

4:3:1 If exposure is continued for eight hours in any one day, and it is to a reasonably steady sound, the sound level should not exceed 90 dB(A).

4:4:1 If exposure is for a period other than eight hours, or if the sound level is fluctuating, an equivalent continuous sound level may be calculated and this value should not exceed 90 dB(A).

4:5:1 In certain circumstances, for example where employed persons move from one area to another, it may be difficult to measure and control exposure to non-continuous sound. If the non-continuous exposure cannot be adequately measured and controlled, any exposure at a sound level of 90 dB(A) or more should be regarded as exceeding the accepted limit and requiring the use of ear protectors. Places where this level is likely to be exceeded should be clearly identified.

4:7:1 The A-weighted sound levels set out above are subject to an over-riding condition that the unprotected ear should not be exposed to a sound pressure level, measured with an instrument set to the 'fast' response,

exceeding 135 dB, or in the case of impulse noise an instantaneous sound pressure exceeding 150 dB.

4:7:2 Other parts of the body should not be exposed to a sound pressure level, measured with an instrument set to the 'fast' response, exceeding 150 dB.

Within industry itself, protection from noise hazard consists in the use of noise baffles on and around machinery and the design, supply and use of personal noise-attenuation devices. With increasing automation throughout many parts of industry, there will possibly be a growing separation of the noise-producing machinery and the workers who monitor its operation. Until then, however, it will remain necessary to protect the worker against damage to his hearing.

For many years there have been improvements in the efficiency of noise-reducing ear-plugs and ear-muffs. These devices tend to reduce noise hazard more effectively at higher frequencies than at lower ones. On the average, well-designed and well-fitted plastic ear-plugs may reduce the intensity of noise entering the ear by about 10 dB to 20 dB at frequencies below 1,000 Hertz and by about 25 dB to 35 dB at higher frequencies, up to approximately 4,000 Hertz. Properly worn, well-designed ear-muffs may reduce noise intensity levels by between about 15 dB and 35 dB at frequencies around 500 Hertz, by between about 25 dB and 40 dB at frequencies around 1,000 Hertz, and by between about 40 dB and 50 dB at frequencies around 4,000 Hertz. Ear-muffs of heavyweight construction are, in general, more effective than ear-muffs of lightweight construction. The most sophisticated ear-protective devices are those designed for specific industrial noise environments in which intrusive noise may be excluded from the ear whilst the wearer is able to hear what he wants or needs to hear. However, even with the best-designed, the most efficient, the most easily worn, the most comfortable of these devices, there will be no protection from noise hazard for the worker who neglects to wear them in all environments in which his hearing is at risk. This happens frequently in some industrial contexts. Little attention has been paid to questions of the workers' attitudes to the risks of hear-

ing loss to which they are exposed and to the ways in which they are encouraged to minimise those risks. The question of inducing a recognition of the benefits of using protective devices, and routine usage of such devices by all workers potentially at risk, is a problem in which the skills of psychologists, managers, and trade union officials need to be combined to find a solution.

There are anecdotes of protective devices of one kind or another that have never left the laboratory work-bench because 'the men will not accept them'. Discrepancies between the value systems of investigators and workers may sometimes frustrate a scheme designed to protect the worker unless attention has been paid to the workers' attitude to that offer of protection. The point has been made from time to time, quietly and without publicity, that sometimes workers, or their representatives, may make a positive choice that they prefer to 'screw' the employers for hazard pay or financial compensation for having to endure hazardous environmental conditions *rather than* support schemes for the reduction of sources of environmental hazard.

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CHAPTER 4

Space

Spatial features of the environment of man at work may be important in two ways. First, they may have an effect upon the way he performs visual and manipulative tasks within his three-dimensional work-space. Second, they may determine, in part, the effectiveness of communication. Human beings do not have extendable arms and legs. Nor are they able to rotate their head through 360° without turning the trunk. Their span of visual attention is not unlimited. Man's skeletal frame is not collapsible. Many restrictions on freedom of movement are imposed by man's structural form. It is therefore necessary to design man's immediate work-space with these limitations in mind.

Attempts to relate the design of machines and their location in the immediate work area to the capacities and limitations of the physical structure and functioning of the worker belong to physical or functional anthropology, while the analysis of measurements of man's physical, mechanical, functional characteristics is part of anthropometry. Anthropometric measurements are made in terms of static dimensions, when the human being is still, and in terms of dynamic features of the human body in action. Aspects of dynamic anthropometry involved in the study of the action of muscle groups are sometimes called biomechanics.

The second aspect of the spatial environment, related to communication and interactions between workers, is a relatively new topic of investigation compared with other aspects of the environment at work. Although it has been acknowledged for some time that, in trying to understand men at work, attention

should be paid to the presence and influence of other workers, only recently have attempts been made to place worker-worker interactions within a quantitative framework.

I *Organisation of Space*

The lay-out of work-space is now attracting great interest. Investigations have been conducted into the spatial distribution of desks, machines, people within offices, conference rooms and work-shops, so as to facilitate communication. A few years ago there was a tremendous enthusiasm for the creation of open-plan work-shops and offices. These designs were intended to help those who were hindered in exchanging information by the physical barriers of their separate working compartments. Removal of these barriers, it was hoped, would permit more effective supervision of operators. Groups of people engaged in mutually dependent tasks could obtain better feedback. In organisations in which the defects of rigid bureaucratic structures were being recognised, open-plan arrangements were expected to yield a sense of common purpose, and shared goals, among members of the work-force. It was thought that a firm in which two employees, differing in function and status, had to communicate with each other by telephone, or through a third party, or by making a special journey along corridors and up or down several flights of stairs, was almost bound to be less efficient than one in which the two employees would have more immediate access to each other.

Many studies of channels of communication, decision networks, information flow diagrams and the like have been made. Critical distances have been calculated so as to promote greater ease of communication without distracting individual workers through the too-close presence of their colleagues. Judicious angling of desks, chairs, work-benches and filing cabinets, as well as the introduction of such appurtenances as potted plants and free-standing trellis work, has sought to provide a sense of privacy without a feeling of isolation. In some organisations, each job or function has been carefully analysed so that each employee could be provided with the 'right' size of desk, number

and size of in-trays and out-trays, 'suitable' dimensions of the immediate work area, 'appropriate' degree of access to and from other work areas, 'correct' amount of screened privacy or openness, 'proper' quality and area of carpet. Complex computer-assisted analyses have been made of the job demands on various strata of employees. The design of open-plan work areas has been one of the most thorough exercises in the effort to match spatial working environments to the functional requirements of the work-force.

Occasionally, after considerable systems analysis and functional planning has preceded the implementation of open-plan arrangements, something appears to go wrong. It may be found, for example, that analysis of job demands has been insufficient. Human expectations have been important too. While, on paper at least, a compromise has been effected between open interaction and privacy, in practice, considerable dissatisfaction is experienced by some workers, who feel that their privacy is being violated by open-plan arrangements that offer anything less than a complete enclosure of the work-space.

When complaints about lack of privacy are examined they are sometimes found to be the tip of an iceberg of antipathy to what is perceived as a threat to established security and status. Some workers feel that they are being 'spied upon' by those of higher status who are now physically present in a common environment. Other workers feel that differentials of status have been reduced when physical barriers between themselves and subordinates are removed. Familiarity is equated with close physical, or visual, contact. This encouragement of familiarity, it is feared, could lead to an undermining of status, a loss of proper respect, a waste of company time spent on social chit-chat or a decline in standards of discipline.

The physical signs and symbols of former spatial arrangements may seem trivial, and unrelated to efficiency, in the eyes of some consultant job-analysts, communications 'experts' and organisational planners. They are, however, sometimes of considerable personal significance to some workers. Recent studies of open-plan offices and work-shops have attempted to take more account of these personal factors. Perhaps the most

important outcome of some early unsuccessful attempts to introduce new spatial arrangements has been a realisation that such changes in working conditions would have a greater chance of success if steps were taken to foster a co-operative attitude among those most likely to be affected by the changes.

II *Social Interaction Facilitation*

Several attempts have been made to discover the optimum arrangements of chairs and desks to facilitate the social interactions that occur in committee rooms, in libraries, in canteens, in recreational lounges, in board-rooms, etc. The effects of *imposed* spatial arrangements on the behaviour of people have been investigated more often among new groups of people meeting for the first time in laboratory settings than among well-established groups of people who have met in consistent circumstances over long periods of time. In these latter contexts, observations have been made of the ways in which people characteristically and intuitively *arrange themselves* for various activities. Less emphasis has been placed on effects on participants of changing these arrangements. Differences in the way different individuals use space seem to be due in part to the nature of the activity in which they are involved and to their cultural background. When distances are determined by the investigator, people have reported their feelings of anxiety, comfort or being threatened during various types of social exchanges.

Many of these studies of social distance and of spatial arrangements are still at the exploratory stage and, for the most part, have not yet appeared among the recommendations on physical environments. In some special situations, such as canteens, libraries, conference rooms and day rooms in hospitals, investigations have been made of the ways in which people using the rooms are affected by the arrangement of the furniture. Even in such special contexts, however, examples of systematic study of spatial variables are comparatively rare.

There has been little reference to any comparisons between men at work and other animal species. Yet there is a considerable literature on the effects of the spatial environment on

many species other than man. 'Territoriality' has been thoroughly explored in terms of some species. But although some similarity may be detected between reactions of some workers, to open-plan offices and work-shops, and reactions of some species to territorial invasion, little attention appears to have been given to the possibility that man may have a need for a 'territory' at work.

III *Spatial Effects on Performance*

Laboratory studies of human and other species in the learning and performance of a variety of tasks have suggested that the physical presence of others as audience, co-actors, co-operators may have a marked effect. Ecologists and others have examined the effects of over-crowding or population density, on the performance and well-being of animal communities and on human urban dwellers. Many of these kinds of studies have implications for designers of the working environment that have not been taken up by investigators. One difficulty in applying conclusions of research has been that of defining the boundaries of the spatial environment occupied by man at work. There are difficulties in describing the limits of the work space of an indoor worker. In outdoor occupations, the spatial environment presents great problems of definition, that have rarely been considered by investigators of working environments.

Consider the spatial environment of, for example, a shepherd whose job is to look after a flock of sheep on a mountain hillside. The shepherd's visual and auditory environment may extend over a radius of many kilometres. Within his immediate spatial environment, there are perhaps several hundred sheep whose activity must be monitored. He must keep his level of vigilant arousal sufficiently high to maintain an adequate level of performance. There may be features in the immediate terrain that pose potential threats to the safety of the sheep. However, there may be potential influences on his efficiency that extend considerably further than the immediate ground occupied by the sheep. Many, widespread sources of visual and auditory signals may need to be incorporated in any comprehensive

definition of the *effective* spatial environment of the shepherd at work. Some potential influences on the efficiency of his performance may be more easily identified than others. Perhaps, for instance, the type of sky under which he works affects his mood, his state of vigilance, or his attitude and his motivation towards his job. If such effects do occur, then presumably the influences that prompt them ought to be included in the description of the working environment of the shepherd as potential influences on his work performance. The problem is that until there have been systematic analyses of the effects of spatial environmental variables on the well-being and efficiency of shepherds and other outdoor workers, there are few *a priori* grounds for decisions to be taken about which features of the spatial environment should, or should not, be included as significant influences on men at work. There are many jobs in relation to which a similar difficulty arises because there has been no exploration of the potential and actual influences from the workers' spatial environment on their performance.

So-called 'modern factories' sometimes include in their recruitment propaganda, details of the architectural layout and landscaping of the factory buildings and their surroundings. Perhaps this is because there has been an assumption on someone's part that these aspects of the spatial environment of the job may have an effect on the recruitment of personnel. Might not such an effect occur in respect of performance efficiency too? Perhaps the multi-storey concrete-block car-park, the refuse-disposal area, the ornamental floral gardens or the view of distant hills or cooling towers, that the worker may be able to see through work-shop windows and doors ought to be included in a description of the spatial environment of the worker. Might not significant influences on the worker be omitted if these aspects of his spatial environment are ignored? Such questions as these have been seldom resolved because they have been rarely articulated. The main concern of investigators, it may be argued, is to identify, quantify, and recommend changes in those intrusive variables in a man-environment system that are amenable to manipulation. Questions of the formal definition of the man-environment system in terms of all its boundaries may

be largely academic. The feature of a worker's spatial environment that attracts the attention of the investigator, and the industrialist who employs him, is that which can be clearly seen to be part of the work area and which is judged to be amenable to control. Many spatial variables have been ignored because they appear to stretch out from the worker's immediate location, because their effects upon performance may be too subtle for immediate quantitative assessment, or because their manipulation and control may require techniques that are not immediately evident.

IV *The Immediate Work-Place*

Within the immediate spatial environment of workers, investigators have attempted to define optimal arrangements of displays and controls. Design and location of controls have been studied against a criterion of optimal levels of energy expenditure. Maximum dimensions of the immediate work-space have been calculated for populations of workers in terms of men's range and speed of movement, their co-ordination of activities and their reaction times. These recommendations about the location and arrangement of component parts of tasks have been particularly important in respect of worker performance in emergencies.

The effect of failure to consider the foregoing factors may be appreciated if we consider the mislocation of electrical isolation switches in some domestic and industrial environments. Not only are some of these switches extraordinarily difficult to find, and reach if found, but the design of the switch itself may leave much to be desired. When a worker has to act quickly in an emergency, it is hardly surprising that an accident results when he has to spend time finding a poorly identified switch which, once recognised, is discovered to be out of reach or directly behind a series of obstacles to be removed or surmounted, and which, once reached, requires the removal of greasy protective covers, the manipulation of rusted safety catches, the grasping of a handle with insufficient space behind it to accommodate easily a man's fingers, and the movement of the handle against a spring-loaded force that is some ten times

greater than that minimally required to prevent the handle position being changed unintentionally.

Without appropriate planning and design there may be many routinely operated control switches, levers or wheels that have been positioned very strangely for operation by mere mortals. If a survey were to be made of machinery in use in some parts of industry today by someone from another world, who made no direct observations of men at work but relied on industrial artefacts from which to draw inferences about the physical characteristics of human workers, an odd picture might emerge. Some machines could lead to an assumption that workers were one metre tall with an arms' span of some three metres. Other machines might conjure up a picture of an operator with three or four arms of various lengths and unusual location. Imagine the design of a worker for whom a machine was suitable which, with the present form of human beings, requires a man to stand on tiptoe to push up a control lever over a specified distance that is only a part of its total range of movement, then to crouch down to make fine adjustments to a calibrated wheel with his left hand whilst his right hand, during the time the wheel is being turned, has to travel from controls situated in the top-right, to the top-left, to the bottom-centre, to the top-centre to the bottom-left and back to the top-right of the machine in a fixed, repeated sequence. Some work-space may be designed so that the operator is required to move back and forth over a distance of three or four metres every few minutes to monitor information from dials about the process of manufacture and to make adjustments to that process at a control console so situated that he loses sight of a key part of the displayed information during manipulation of the controls.

Such examples as these may appear to have a greater affinity to the fantasy worlds of Chaplin, Emmett or Tati than to any real-life industrial conditions. Unfortunately, these hypothetical cases may be all too real in some work-shops. There have been many decades of acceptance of engineering, rather than anthropometric, criteria of successful machine and process design. In this light, it may be less surprising that there exists in industry some hardware that almost seems to invite under-productivity,

muscular fatigue, performance errors or minor accidents to workers. Replacement plant and machinery created for new industrial processes may sometimes be an improvement in that greater attention has been paid to the characteristics of the worker population for which it is intended. However, such improvements have been far from universal in the world of industry. From time to time new plant has been installed which is functionally little different from that it has replaced even though it may look shiny, clean and new.

V *Application of Anthropometry*

It is probably in the establishment of new industrial concerns, or where complex technological equipment is being created, or in situations in which optimum performance of personnel is crucial to success, as in some military operations, that anthropometrically-designed equipment is most likely to be found. When these conditions obtain they cannot of themselves ensure improvement in machine design. It is also necessary for adequate information to be available about the anthropometric characteristics of the worker population. At present there are few worker populations that have been studied anthropometrically. If the work-space designer wishes to improve his designs he may be faced with the task of undertaking a large anthropometric survey. He will not need to know details of all the physical characteristics of the workers for whom he is planning. The particular features of the workers that will interest him will be those that are most closely related to the tasks to be performed. A wide range of anthropometric measures is potentially available to him.

In the past, designers have found it useful to take note of data on sitting or standing height; arm length; arm reach in a forward, sideways or other direction; hand or finger size; knee height; strength of individual muscle groups; range of movement possible at various limb joints and grip strength. Some of the measures used by designers have been those of the static, naked or clothed, human body. Some measures have been related to the body's movements in terms of range, strength or

compatibility. In assessments of body and limb movement, the designer may need to know, for a given population, the degree of turn possible towards the mid-plane of the body (medial rotation) or away from the mid-plane of the body (lateral rotation). He may want information on the range of movement possible towards the mid-line of the body (adduction) or away from it (abduction). There are limits, which vary between people, to the angles through which parts of the body may be moved closer together (flexion) or further apart (extension). In some tasks, where manipulative skills are called for, it may be necessary for the designer to obtain data on the degrees through which the palm of the hand may be rotated downwards (pronation) or upwards (supination). Biomechanical assessments may be required for the operation of particular muscle groups that mediate hand-grip strength or foot-pressing, either on a single, short-lasting occasion, on repeated occasions at given time intervals, or continuously over specified periods of time.

The objective in collecting anthropometric data is usually to obtain information on the distribution of characteristics within a specified worker population. Machines that have been designed to accommodate men of *average* reach, or *average* sitting height or any other *average* measure, will be unsuitable for many workers. What the anthropometrist aims for is a description of the range of measurements for a given dimension so that machines may be designed to accommodate a chosen proportion of workers within that range. On some occasions, the designer may be requested to arrange a 'fit' between machine or work-space and workers for 70 per cent, or 90 per cent, or some other percentage, of the work-force. For this purpose, an average value is inadequate and a knowledge of the largest and smallest values is equally insufficient. It is necessary for the designer to know how such measures as arm length, standing height, degree of neck flexion, are distributed among the population of workers.

An example of a simple task with which a designer may be faced may serve to illustrate the kind of procedures involved in an anthropometric exercise. An anthropometrist may be asked to design a work-space in which the worker stands upright in

front of a work-bench. One part of that work-space may be a control switch that needs to be placed at approximately shoulder height directly in front of the worker's right shoulder and as far as possible away from the worker. The worker will be prevented from leaning forward to operate the switch because of the height of the work-bench in front of him. How does the designer decide on the location of that switch?

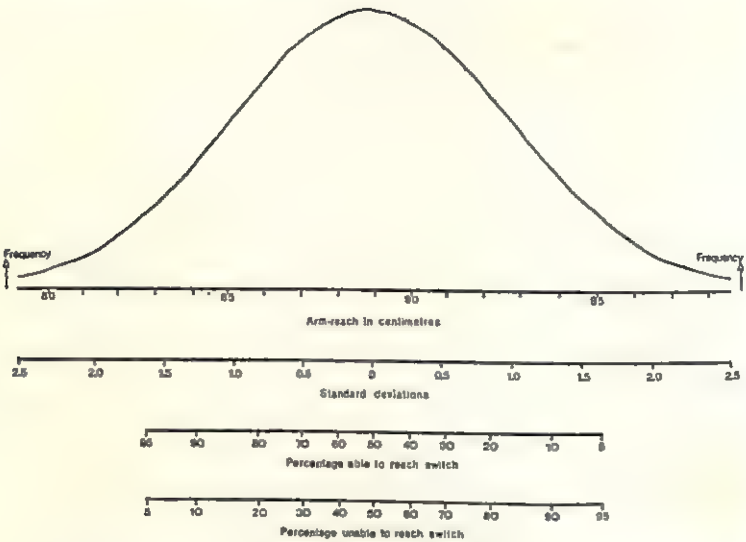
Two anthropometric characteristics of the particular work-force that will occupy the work-space being designed seem to be immediately relevant. The designer needs to know, at least, the distribution of shoulder height and the distribution of arm-reach among the workers. In the present example, we may consider arm-reach. Arm-reach measurements have been published for several samples of worker populations. It may be possible for the anthropometrist to use some of these data and thus save the time and expense needed to conduct a direct anthropometric survey of a sample of the work-force for whom he is designing. In the data available, the length of arm-reach may have been defined for a sample of workers as the distance from the vertical line of the back of the right shoulder to the line of the tip of the middle finger of the right hand when the man is standing upright, is unclothed, and is stretching out his right arm and hand directly in front of his right shoulder.

Among these data, an average arm-reach of 88·9 centimetres might be found. If the designer chooses this value on which to base the location of the control switch then half of the workers will be unable to reach it. The data may also show that less than 1 per cent of the sample had an arm-reach greater than 101·6 centimetres. If the designer chooses this figure on which to base the location of the switch, which has to be placed as far as possible in front of the worker, more than ninety-nine out of every hundred workers will be unable to reach it. At the other end of the range of arm-reach values, the data may indicate that less than 1 per cent of the sample had an arm-reach that was less than 78·9 centimetres. If this value is used to locate the control switch, although the vast majority of workers will be able to operate it, the criterion of placing the switch as far as possible away from the man will have to be largely ignored.

In order to identify an appropriate location, therefore, it is necessary for the designer to know the distribution of arm-reach values around the average value.

A measure of the distribution of arm-reach values in a sample of workers may be calculated. The difference between each individual arm-reach and the average arm-reach of the sample is taken. Each of these differences is squared and the average of the squared differences is found. The square root of that average provides a statistic called a root mean square of the individual differences. If the sample of workers, whose arm-reach has been assessed, is large, the root mean square value may be close to the *standard deviation* of the distribution of arm-reach data in that population of workers. Depending upon the shape of the distribution of arm-reach values, the designer may have enough information to choose a location for the switch if he knows the average (say 88·9 centimetres) and the standard deviation (say 3·8 centimetres) of the arm-reach values of the population of workers who will be required to operate the control switch. If the arm-reach values form a 'normal' distribution, the designer knows that he can predict what proportions of workers will have a longer or shorter reach than any given arm-reach length. The relation between arm-reach values and proportions of workers able, or unable, to reach any specific switch location is shown in the diagram on page 80.

The designer would know from the 'normal' distribution that if the control switch were placed at an arm-reach value of 85·1 centimetres, 50 per cent of workers who had an arm-reach of at least the average length of 88·9 centimetres would be able to reach it and that, in addition, there would be another 34 per cent who could reach it because their arm-reach was between the average length and one standard deviation less than the average length. Thus a switch located on the basis of an arm-reach value of 85·1 centimetres could be reached by 84 per cent of the work-force. Various other proportions of the worker population could be accommodated by basing the location of the switch on arm-reach values that were appropriate multiples or fractions of the standard deviation of the distribution of arm-reach values.



Once an arm-reach length has been chosen, as a compromise between accommodating an acceptable proportion of workers and achieving a maximum distance from the worker, further adjustments may still have to be made to the chosen arm-reach figure. If the switch has to be flipped up or down, about one centimetre has to be subtracted from the chosen arm-reach value. If the switch has to be pushed away from the worker, about 2·5 centimetres may need to be taken off the chosen arm-reach value. About 7 centimetres less than arm-reach is required if the switch has to be turned with the forefinger and thumb. As much as about 12 centimetres adjustment to the chosen arm-reach value may be necessary if the worker needs to grasp the control switch with his whole hand. Further amendments to the arm-reach length chosen as a basis for the location of the switch may be required to take account of: (i) differences in clothing between the reference group of workers and the operatives of the switch; (ii) differences in body girth of the men who will stand at the work-bench; (iii) differences in the reach of men whose shoulder height requires them to reach down to or reach up to the switch in addition to reaching for-

ward to it; and (iv) differences between men in their finger strength or finger dexterity. However, provided suitable data are available, the designer may achieve an anthropometrically appropriate design after a straightforward, if rather tedious, data-manipulation exercise.

It would be a mistake to assume from this example that anthropometric data are available for most worker populations. At present, there are, in the anthropometric literature, fairly comprehensive profiles of the physical characteristics of rather limited samples of worker populations. Military personnel, students and athletes, figure prominently in tables of comprehensive anthropometric data. Housewives and school-children occur quite frequently in tables of anthropometric data concerned with a few selected dimensions of human physical stature and functioning.

One aspect of industrial growth that has brought about an increase in the available data has been that concerned with the export of machinery and vehicles for use by populations that are anthropometrically different from the worker populations of the manufacturing countries. In general, however, the work-space designer will be faced with a situation in which nothing is known about the anthropometric characteristics of most groups of workers, a little is known about several groups of workers, and quite a lot is known about the anthropometric characteristics of a very small minority of groups of workers.

VI *Design of Work-Space Utensils*

A similar development to that of improvement in work-space design, based upon physical anthropometry, has been one concerned with the design of the utensils and furniture of the work-space. An effort has been made, for example, to match the operation of emergency controls with the expectations of the workers who will operate them. In Britain, there appears to be a general assumption that switch movement in an upward direction means something is being switched off and movement in a downward direction indicates a switching on. Movement of a control leftwards, or in an anti-clockwise direction, is

associated with an expectation that whatever is being controlled will decrease, and that a rightwards or a clockwise movement will produce increase. There are many more instances of stereotyped expectations. Some expectations appear to be firmer than others and, in some respects, quite contrary expectations may be found between different cultural groups. This latter fact may pose problems for designers of equipment for mixed indigenous and immigrant worker populations.

From the beginning of this century, investigations have been made of the relative compatibilities and incompatibilities of manipulative movements performed simultaneously or successively. In recent times, this line of research has progressed to include studies of compatibility of various modes of communication and information processing. The concept of 'overload' in the human system has been introduced to describe those occasions when a deterioration in efficiency of performance has resulted from too many conflicting and incompatible demands made on the worker. In order to reduce task demands, to a level at which the processing efficiency with which information is dealt with is compatible with the limitations and capacities of workers, studies have been conducted into the effects of various types of information presentation. Rapidity and accuracy of information handling has been taken as a criterion against which the appropriateness of digital, meter and clockface forms of presentation of information may be assessed. On the control side of the display-control interface at the work-place, considerable research effort has been devoted to the investigation of optimal designs of control levers, switches and knobs. The criteria of successful design have been concerned with matching the purpose and function of the control with the dexterity and sensitivity of human manipulative movements.

From time to time, a problem has arisen of designing a flexible structure for a work-place. There has been, for instance, much study of the design of adjustable chairs and work-stools. The range of adjustment required to accommodate a specified proportion of the work-force is derived from an examination of anthropometric data. Unfortunately, as in many other instances of so-called applied research, more attention has sometimes been

paid to the completion of a laboratory study of the application of anthropometric and engineering data to the design of adjustable chairs than to the question of how workers might be persuaded to adjust the chair supplied to them to their individual requirements. Anecdotal evidence suggests that it is not unknown for adjustable seating to be introduced into a work-place and be subjected to considerable, unguided manipulation by the first worker to occupy the seat. Thereafter, the seat may remain unchanged for years despite the fact that a tremendous variety of occupants may use it over that time. Even when the seat is first accepted enthusiastically by a worker, he may not use the seat to its best advantage without instruction. Thus the back-rest provided on an especially well-designed seat may provide none of the back support it was intended to give either because the worker is given no guidance about how to adjust the back-rest to give him maximum support, or because he prefers to sit forward on the front edge of the seat, or because he has removed the back-rest because it interfered with his freedom of movement to lean back to exchange conversation with a fellow-worker further along the assembly line.

The question of promoting schemes to encourage workers to form the habit of utilising those aspects of his work-space that have been designed specifically for his efficiency and well-being has not been considered so frequently. It is necessary not only to instruct the worker in the benefits to be gained from proper use of designed facilities but also to teach him to assess the 'fit' between himself and the work-space he occupies. Follow-up studies of the implementation of recommended changes in work-space design would seem to be an essential part of the investigator's function. Yet systematic studies of 'recommendations in action' are the exception rather than the rule in many aspects of industrial applied science. The continuous assessment of technological advance within factories and the influences of applied scientific research on changing conditions within factories is an important aspect of the application of scientific research to industry.

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CHAPTER 5

Temperature

Man's environment at his place of work may impose stresses on his thermoregulatory functions. Man, like other warm-blooded species, is a homeothermic organism. This is to say, that maintenance of internal temperature conditions within a fairly narrow range is necessary for the efficient functioning of his vital organs, particularly his brain, and ultimately for his survival. In order to maintain a fairly constant internal environment in the face of exposure to less than ideal external environmental conditions, man is endowed with: (i) a complex, physiological, thermoregulatory system that is capable of adaptation and acclimatisation to sustained changes in external environmental conditions; and (ii) a repertoire of behavioural and cultural responses and skills that enables him to take action to reduce or prevent the strains to which his physiological system might otherwise be subjected.

I *Thermal Environmental Effects*

The range of thermal environmental conditions and hazards, that men at work may be subjected to, is such that investigations have called for a variety of criteria for assessing the need for scientific intervention into industry. Most intervention has been concerned to establish limits of exposure. The protective limits have tended to be different for various degrees of severity of thermal stress. Sometimes, the combination of environmental conditions and the job to be performed has made it appropriate

for limiting conditions to be expressed in terms of either *physiological strain*, or *performance efficiency*, or *subjective experiences*. A limit based on physiological strain is designed to maintain the body's thermal equilibrium or to minimise the risk associated with loss of that equilibrium. Performance efficiency is defined in terms of maintenance of output in quantity or quality or minimisation of errors in task performance. Criteria related to subjective experience are associated with feelings of thermal discomfort consequent upon exposure to warm or cool environmental conditions.

It appears that, whichever criterion is adopted, there are wide differences between individuals in their responses to thermal environments. Some attempts have been made to discover the sources of these differences, but apart from fairly gross variables such as physical fitness, acclimatisation and level of skill, the search for a precise explanation of individual differences has not been successful. It may be because precise hypotheses, concerning the origin of individual differences in responses to thermal stress, have not been formulated by investigators in this field that the question of the extent of differences between individuals in some aspects of their thermal responses has been ignored. Perhaps some psychologists, because of the nature of their training, are more concerned to seek distributions of human responses than, say, are some physiologists. It would be generally agreed, however, that conclusions expressed in terms of 'average' responses of 'average' men may be misleading if transposed without caution to diverse industrial populations.

II *Intolerably Hot Conditions*

Evidence, from epidemiological and clinical studies of fatalities and near-fatalities due to hyperthermia, suggests that if unprotected, unfit, unacclimatised workers perform work in hot conditions so as to produce a rise in body temperature to about 42° C, there may be a high risk of delirium, convulsions, and death. The incidence of casualties will tend to be less if workers are physically fit, have been acclimatised to the specific work routine and thermal stress conditions, and are given imme-

diate treatment by well-qualified and experienced medical personnel.

In laboratory research, on human volunteers and on preparations designed to simulate the ways in which transfer of energy occurs in human tissue, it has been found that skin temperatures of about 44° C or 45° C are associated with an experience of intolerable pain, and that if the exposure is continued tissue damage will increase. Abrupt exposure, to environments giving rise to these effects, appears to produce intolerable pain at lower skin temperatures than does exposure in which the rise in skin temperature is gradual.

Research into the design of respirators has indicated that inspired air at wet-bulb temperatures in excess of 45° C to 50° C creates distressful pain in breathing. Without respirators, similarly painful experiences in breathing, and in exposed skin, are found to be worse when the movement of the environmental air is greater. Some relief may be obtained in these environments by instructing workers to breathe slowly and shallowly. However, safe entry into industrial environments such as these is really only possible when workers are provided with especially designed protective garments.

Protective garments for work in high temperature environmental conditions may incorporate in their design both reflective and insulative barriers to radiant heat energy. They may also include a system of circulation of cooled air or water, within the garment, to provide a tolerable micro-climate for the worker. There are several efficacy criteria that may be adopted in evaluating these protective devices. Efficacy may be judged in terms of the kind of criteria used in the science of clothing materials – where questions of the flammability, water or air permeability, wear and tear strength, insulative properties of the materials used and their assemblage are considered. Physiological efficacy may be judged from a comparison of external temperature conditions with the level, and rate of rise, of skin and body temperatures of the wearer. The efficacy of garments in terms of the ability of workers to maintain their balance in high air movement may also be assessed. Where work calls for great physical effort, the effect of wearing a heavy protective

garment must be considered. Where the job requires the maintenance of skills that are physically less demanding, the efficacy of the garment may be judged against criteria such as the extent to which the garment interferes with successful job performance by reducing the wearer's manipulative, auditory or visual functioning. Cultural and social criteria may be important in assessing the efficacy of protective garments within factories. The attitudes of potential wearers, to the garments provided for their protection, may have a marked influence on their willingness to adopt their routine use. In some studies of the design of protective garments for workers in extremely hot and hazardous environmental conditions, some of these criteria of efficacy have been ignored.

III *Severe but Physiologically Tolerable Heat*

In some situations in industry, conditions exist in which extreme thermal environments occur against which workers are not provided with the protection of especially designed garments. In these situations, in which all men are uncomfortably hot, attempts have been made to try to establish limits, to protect men from medical and physiological danger, in terms of *either* duration of physiologically safe exposure to environments that cannot be reduced in their thermal severity *or* upper limits of thermal severity to be permitted for specified durations of exposure. In the former, three questions have had to be faced. The first concerns a choice of human physiological response that will be taken as the criterion for deciding that a limit of thermal tolerance has been reached. In some investigations, it has been decided to continue the exposure of men to extreme heat until they become unconscious. In other studies, the investigators have decided to take as the limit of exposure, the attainment of some specified level of rectal, oesophageal, tympanic, oral, or ear temperature. Most studies have used a combination of several indices of thermal strain as an exposure physiological 'end-point' criterion. Secondly, whichever criterion of the limit of physiological strain is adopted, investigators have to decide on how a 'safe exposure' should be defined. In some studies,

a definition of safe exposure duration has been chosen that is some specified interval of time shorter than the average time to attain the state of intolerable physiological strain. In other studies, safe exposure has been defined as that duration for which most workers will not suffer intolerable strain. In a few investigations, a statistical exercise has been conducted from which it has been possible to protect various proportions of men from reaching a state in which they might lose consciousness or might attain a given level of body temperature. The third question, to be considered by investigators, concerns the quest for some way in which those men who are most likely to be at risk during exposure to very hot working conditions might be identified *before* they have suffered thermal strain. Apart from suggestions that men who are unfit physically, who are obese, suffer from respiratory or cardiac weaknesses, or have some form of sweat gland dysfunction, should not be exposed to extreme thermal conditions, little is known about the sources of the individual differences in responses of workers to thermal stress. In one sense the plight of workers with low heat tolerance is a problem that tends to solve itself in that such workers tend to move away from hot industries in which there are the hot conditions that are potentially dangerous to them. Workers in those parts of industry, in which thermal strain is a prominent feature, may be a self-selected sample of the heat-tolerant work force. Within a heat-tolerant population of workers, however, there are still great differences between workers in susceptibility to the adverse effects of exposure to hot working conditions. The origin of this variation may be a complex interaction, of anthropometric, medical, physiological, motivational and emotional factors, the precise nature of which has still to be elucidated.

Let me illustrate the kind of investigation that may be conducted on these problems. In 1961, a request was made to a team consisting of doctors, physiologists and psychologists to enquire into the possibility of producing safe exposure times that would enable men to carry out emergency repair work in extremely hot environmental conditions. Two constraints were placed upon the investigation. One was that the men would be

required to perform moderate to hard physical work during the exposure and yet be capable of leaving the environment unaided when the safe duration of their exposure had elapsed. The other constraint was that no special protective garments or acclimatisation procedures would be available for the men.

A search of the literature failed to reveal any established basis for making appropriate recommendations within the constraints mentioned. Evidently, there was a point at which thermal severity became so great that men would be unable to enter some environments because of immediate pain in breathing and where skin tissue was exposed. In moderate conditions, when men had been able to endure exposure for two to four hours, their rate of approach to a state of heat collapse was extremely slow. There appeared to be no generally acceptable way of combining environmental variables into a single index of thermal severity over this range to be studied. Finally, a wide variety of criteria of intolerable strain had been hitherto employed. It was decided, therefore, that the proposed investigation should be designed specifically for its relevance to the context in which the problem of safe exposure had occurred.

Men were recruited to participate in the study from the workforce at risk. They wore normal working clothing and performed physical work at a level of energy expenditure comparable with that in the actual situation. A range of environmental severity was selected that reflected the varying air temperature, humidity and air movement that might occur at work. Since machinery noise had normally to be endured by the workers, a tape-recording of this noise was made for use at a comparable level of intensity during the investigation. A method of evaluating degree of strain was devised which would enable a man to be withdrawn from exposure to stress just before he collapsed. This end-point criterion, it was hoped, could be used consistently by observers throughout the investigation. Continuous recordings were made of the body temperature of the men exposed to the thermal stress.

In the first part of the study, the responses of eight men to six levels of environmental thermal severity were recorded. These men differed considerably in the time they took to reach

a state of near-collapse in each of the environmental conditions. Preliminary recommendations could be made on the basis of the data collected thus far, but it was felt that a greater number of participants was necessary to achieve a more realistic estimate of the extent of the variation between men in their tolerance of heat. The second part of the study obtained the responses of a further thirty-one men to a new selection of environments. Finally, because nearly all the environmental conditions explored had been those with high levels of humidity, it was decided to complete the study by examining the responses of a further forty-eight men to a further selection of environments within the original range.

By the end of the enquiry, data had been collected in twenty-seven different thermal environments and over four hundred individual responses had been recorded. By then, several years had elapsed since the request for recommendations had first been made. The physiologist had left the team to take up an appointment elsewhere. One of the two psychologists had changed his job and country of residence. Four statistical advisers had come and gone. The medical member of the team had also left to take up his duties elsewhere and had been replaced. Three liaison committees, in succession, supported the research and maintained the request for recommendations about safe exposure times. The data had been produced at a cost of more than £20,000 and the equivalent of about six months' full-time research by a team of scientists and supporting technicians. Each of the eighty-seven men who participated in the study had endured the unpleasant experience of being stressed almost to his limit on several occasions, and it could hardly have been adequate compensation for some of them to witness the spectacle of one of the investigators who collapsed in the heat.

At the end of the series of investigations, it was possible to establish a statistically appropriate description of environmental thermal severity for the range of environments studied. A general equation was formulated that related 'times to near-collapse' to an index of thermal severity. The distribution of individual differences in tolerance of thermal strain around average tolerance values was determined. Recommendations were made relating

durations of exposure to environmental severity, within the range studied, that would be safe for 50, 75, 90, 95 or 99 per cent of exposed workers. These recommendations were suitable only for those workers who had been adequately represented by the men who took part in the investigation. They could not be directly applied to older or to less fit workers. The responses of acclimatised men (*or* men working at a different level of energy expenditure, *or* men exposed to environments in which there was different air movement, *or* in which there was a significant radiant heat factor, *or* men who had to return into the environment after recovering for a given length of time from their first exposure) would not have been properly reflected in the data produced in the research. There was, apparently, no way of predicting whether a particular man would be highly tolerant or highly intolerant of thermal strain. Yet there were marked individual differences in the time men took to reach a state of near-collapse in every exposure. Some indication of this range of tolerance might be gathered from the recommendations that, for instance, in an environment, saturated with water vapour, at an air temperature of 40° C, 99 per cent of men would not suffer near-collapse if all men were withdrawn from the environment after 16 minutes; 95 per cent of men would be safe for 20 minutes; 90 per cent for 22 minutes; 75 per cent for 26 minutes; and 50 per cent if exposure was terminated after 32 minutes. In environments equivalent to a saturated temperature of 35° C, a comparable range of recommended safe exposure times ranging from 35 to 68 minutes was found.*

In conditions more severe than about 33 to 35° C, all workers risk heat collapse. Investigations have produced recommendations about exposure durations that minimise this risk of collapse. When environmental temperatures are not quite so severe, investigators have attempted to specify the working conditions in which most men should be able to complete a work-shift of four, six, or eight hours. Limits recommended have been based upon studies of the extent to which a combination of hard physical work and environmental stress is compatible with

* This investigation has been fully described in an article in the journal *Ergonomics*, 1971, Vol. 14, pp. 733–57.

maintaining a fairly constant, though possibly slightly elevated, body temperature. Rectal temperature is usually taken as an index of thermal strain. Relatively small samples of men have been studied for some of these recommendations, but for others larger samples have been required in order to take account of individual differences in ability to withstand extreme heat.

It has been recommended, for example, that *acclimatised* men may be allowed to work an eight-hour shift in environments up to 32·2° C saturated, provided the physical effort demanded by their work is moderate or light. For moderate to heavy work, an upper limit of 30·6° C has been recommended for acclimatised men working an eight-hour shift. If men are required to perform heavy physical work over an eight-hour shift, environmental severity should not be greater than that represented by a saturated environment of 28·9° C. For *unacclimatised* men, working at comparable levels of energy expenditure over a eight-hour shift, corresponding recommendations have been made of upper limits of environmental thermal severity of 30·2° C, 27·4° C and 26·9° C, respectively, for the three levels of work load.

Below these limiting conditions, workers may feel uncomfortably hot. The performance of skilled tasks may deteriorate. The men are, however, safe from physiological distress, provided the environmental limits are not exceeded. Some of these recommendations have been incorporated in safety regulations and occupational-hazard bonus payment schemes of selected heavy industries in the United States and on the continent of Europe.

IV *Effects on Task Performance*

The derivation of environmental limits of thermal stress, that may be tolerated by men engaged in physical work, has been based mainly on the study of body temperature. Less attention has been paid to body temperature when the effects of heat on the performance of non-physical tasks has been studied. At the levels of thermal severity at which there is little danger of heat collapse, much use has been made of an index of environmental

warmth called the 'effective temperature scale'. In view of the widespread acceptance of this measure, and in view of the ever-present evidence of wide individual variability in responses to thermal environments, it may be useful to give an account of the development of the effective temperature scales.

The research began in the first quarter of this century. The original investigations were concerned with the effects of different combinations of thermal environmental variables on sensations of warmth. In the first series of studies, two psychometric rooms were used in which it was possible to vary, independently, the air temperature, humidity and air movement in the rooms. In one of these rooms, an environment was created in which there was still air, low humidity and high air temperature. In the second room, the environment also had still air conditions, but with high humidity and low air temperature. Three people participated in the study. Their job was to pass back and forth, between the two rooms, recording the temperature and humidity conditions in each room, and judging whether the sensations of warmth evoked by the two environments were similar or different. Whilst the three observers passed back and forth between the two rooms, the conditions in the second room were gradually changed until the two environments were judged by the three observers to give equivalent sensations of warmth. Recordings were made of 440 pairs of environments that had given rise to similar warmth sensations. The investigators then plotted the pairs of environments, giving rise to equivalent warmth sensations, on a chart with the axes of air temperature and humidity.

When the chart had been completed, two confirmatory studies were undertaken. In one, the two rooms were given environments that were expected to elicit different responses, despite the fact that the wet-bulb temperature in each room was the same. Eight people participated in the study. All eight agreed that the two environments did not give similar sensations of warmth. In the second of the studies, the environments of the two rooms were chosen so as to give similar sensations of warmth, even though the air temperature and humidity of the two rooms were different. Eight people passed back and forth between the two rooms. Of the eight, four agreed that the two

rooms felt the same and four agreed that the two rooms felt different.

Using the original chart of various combinations of air temperature and humidity giving similar sensations of warmth, the investigators went a stage further and varied the air movement in the two rooms. Again, pairs of environments giving similar sensations of warmth were identified. At the end of this stage, further data were plotted on the psychometric chart to indicate how air temperature (dry-bulb), humidity (wet-bulb), and air movement values could be combined in various ways to give similar sensations of warmth. All the studies, thus far, had been conducted on people who were stripped to the waist. Similar data were obtained for men wearing light indoor clothing. Twenty years or more after the first of the investigations, the influence of radiant heat sources was taken into account.

There are now two scales of environmental conditions that are said to correlate with feelings of warmth. One is the Corrected Effective Temperature (CET) Basic Scale, for men stripped to the waist, and the other is the Corrected Effective Temperature (CET) Normal Scale, for men dressed in light indoor clothing. The range covered by the Corrected Effective Temperature scales is from 0° C to about 40° C, though doubt has been expressed about the accuracy of extreme CET values. The CET values used are those of the air temperature of a still air environment, saturated with water vapour, and all other combinations of temperature, humidity and air movement that are said to promote similar sensations of warmth. Apart from the study of the responses of the eight people, reported at an early stage in the development of the CET scales, there appears to have been no confirmatory study of the warmth equivalence of the variety of environments that may be described by any given CET value. The CET scales were constructed from the reports of a few people judging whether pairs of environments felt equally warm. Since then, they have been used extensively to establish comfort zones for various large populations. Only recently have some investigators begun to ask whether pairs of environments judged to be equally warm will necessarily be equally comfortable. It could be that combinations of tempera-

ture, humidity and air movement giving warmth equivalence may be different from combinations giving discomfort equivalence.

In defence of the CET scales, it must be acknowledged that, despite their widespread use in laboratory, industrial and domestic studies, no reports have appeared which indicate that the scales are grossly misleading evaluations of thermal warmth *or* thermal comfort. This may be because responses to environmental warmth are fairly coarse and produce a relatively loose 'fit' between man and his thermal environment. If so, the CET scales may be quite adequate for the purposes for which they have been used. However, if the 'fit' were really such a loose one, it would be surprising to find that individual differences were a prominent feature of studies of comfort zones. Yet almost every study has reported extensive differences between people in their comfort-discomfort and performance responses to thermal conditions.

Performance, in a variety of manipulative, psychomotor, vigilance and other mental tasks, has shown, in general, a statistically significant deterioration in laboratory environments warmer than about 27° C CET. Measures of performance have included errors of omission or commission, accuracy, and output per unit time. In view of the fact that considerable variation has been found in the susceptibility of an individual's performance to the adverse effects of environmental conditions, it is important to note that deterioration in performance beyond this CET value has been established, statistically, for *groups* of workers. Thus, some individuals may show little deterioration in performance and others may show much. In some studies, no significant loss of efficiency has appeared at environmental levels in excess of 27° C, when workers were acclimatised, highly skilled at their task, or working at their own pace. In other studies, significant deterioration in performance has been shown in conditions less severe than 27° C, when workers were unused to work in warm environments, were highly motivated to expend considerable effort on the task, but were asked to engage in an activity for which they had little skill or expertise. Occasionally, studies have been reported in which performance of some tasks

has improved when workers have been subjected to levels of environmental warmth comparable to those which may produce a deterioration in the efficiency of performance of some other tasks.

In the United Kingdom, from 1919 onwards, much research was sponsored for the Industrial Fatigue (Health) Research Board (now defunct) by the Medical Research Council and the Department of Scientific and Industrial Research. Many aspects of men at work, and their industrial environments, were examined and some of the studies were concerned with thermal effects. The reports, more often than not, bear witness to the problems of 'field' research. Difficulties in obtaining complete records in industry, in collecting quantitative data at the actual place of work, in identifying and assessing the influences of significant variables in the work-shop, and in reaching conclusions from a single case-study from which one might generalise to other situations, are clearly shown in these historically valuable reports.

The Industrial Fatigue (Health) Research Board took note of many different effects of environmental conditions on workers. In some reports, it was concerned with productivity. In others, environmental effects were assessed against criteria of worker well-being. In others again, the frequency and severity of accidents was the criterion chosen. In a study of mill workers, it was shown how a compromise must sometimes be reached between the high humidity demand of a process, such as the need to keep breakages down to a minimum, and the low humidity demand of the worker, so as to avoid loss of efficiency through discomfort.

From the data produced by the Board, and in other studies, it appears that, in general, there is a critical level of environmental temperature of about 23° C CET. When it is warmer than this, there is a tendency for output to fall and for absenteeism and minor accidents to increase in frequency. These effects appear to be more marked in the youngest and oldest members of the work-force, and when a long period of relatively cool conditions is suddenly interrupted by a spell of hot weather that produces working conditions in excess of 23° C CET.

Much more research, however, is still necessary before we have anything like a complete picture of the effects on workers of exposure to an abnormally warm environment.

V *Comfort and Discomfort*

Large samples in Europe and in the United States have been studied in order to establish limits of environmental warmth beyond which people experience discomfort. Data from these studies indicate that the environmental limit of Corrected Effective Temperature, beyond which a given proportion of people suffer thermal discomfort, varies with: (i) the season of the year; (ii) the geographical location and its usual climatic characteristics; (iii) the clothing habitually worn, which may account for most of the sex differences in responses; (iv) the activity in which the sample under study is engaged; and (v) the method by which thermal discomfort is assessed.

Various techniques of assessing comfort-discomfort have been employed. In some studies, unstructured questionnaires have been used in which respondents describe their thermal comfort. In others, an experience of thermal discomfort has been assumed to be concomitant with the appearance of sweat on the body. Many studies have directly asked people how they feel by using certain types of scaling techniques. A fixed-choice scale may be used in which the respondent is asked to record, for example, which of the following descriptions fits the immediate thermal experience:

Much too warm
Uncomfortably warm
Mildly warm
Neither too warm nor too cool
Mildly cool
Uncomfortably cool
Much too cool

One of the problems in the use of this kind of scale is that it is impossible to know how much difference there may be between

the experience associated with any two adjoining response categories. To obviate this difficulty, in some studies a continuous scale is used in which the respondent is asked to mark, on a line, the point between the two extremes which most closely corresponds to his thermal feelings:

Unbearably hot ———————— Unbearably cold

or:

Totally comfortable ———————— Totally uncomfortable

Another form of scale is that which requires the respondent to make comparative judgements such as:

I would prefer to be warmer than I am now
I would prefer to be cooler than I am now

Many assessments of thermal discomfort have been made using one or other of these various techniques. Little is known about whether conclusions based on one method of questioning people are likely to be similar to conclusions based on the use of a different method. One study has suggested that the limits of human comfort could be simply defined as a thermal 'plane' bounded by conditions that produced sweating at one extreme of temperature and shivering at the other, and conditions that produced dry nasal passages and a dry throat at one extreme of humidity and condensation from the environment on to the person at the other.

From verbal replies to questions, it appears that, at one extreme, 28·3° C CET was 'too warm' for an entire sample of male Americans stripped to the waist. An environment, at another extreme, of 17·2° C CET was the upper limit of comfort for 70 per cent of a sample of 2,000 working women in Britain in winter. Between these two temperature values, many studies suggest different upper limits of comfort for different populations. There was a reduction in the number of complaints made by Members of Parliament in London some years ago, when the hot air in the debating chamber of the House of

Commons was reduced to a temperature of 19·7° C. However, in 1973, there were further complaints that conditions were uncomfortably warm. One Member of Parliament attributed the 'irritable and angry outbursts' and 'the number of MP.s who sleep or drop off during a debate' to the warm temperature. A recent recommendation for industry was to the effect that the lower to upper boundary conditions for ensuring that at least 80 per cent of British sedentary workers would not suffer thermal discomfort should be 16·7° C CET to 21·8° C CET in summer and 15·5° C CET to 20·7° C CET in winter.*

VI *Optimal Thermal Environments*

In general, the harder the physical effort required of workers and the more experience they have had of cold, the lower the temperature may be which is most suitable for them. Similarly, if light work is performed when workers have become used to warm conditions, the ideal working environment will tend to be warmer. In the United States, it has been suggested that 'most' people are comfortable at air temperatures within the range 20° C to 22° C, with relative humidity values of between 40 and 60 per cent, and air movement within the range 0·13 to 0·18 metres per second.

In the United Kingdom, it has been suggested that an air temperature of 19·5° C to 20·0° C would be suitable for clerical workers. For general office workers an air temperature of 18·3° C to 19·5° C; for active workers in light industry an air temperature of 15·5° C to 18·3° C; and for workers in heavier industries an air temperature of 12·8° C to 15·5° C has been recommended. At air temperatures near 18·3° C, relative humidity should be maintained within a range from 30 to 60 per cent. Air movement should be provided that varies randomly within the range of 0·06 to 0·15 metres per second, around an average air movement of about 0·11 metres per second. A temperature gradient should be achieved such that workers are provided with a cooler temperature at their head-height than

* These recommendations were published in an article in the *British Journal of Industrial Medicine*, 1971, Vol. 28, pp. 259–64.

at ground level, but the difference between these two air temperatures should be kept less than 3° C. If underfloor heating is provided, this should not produce a surface temperature of more than 25° C. To avoid a feeling that the air is stuffy and stale, wall temperature should not be allowed to fall below the temperature of the air, and a ventilation system should be provided that will supply between 17 and 28 cubic metres of fresh or purified air per hour per person. More fresh air will be required in summer than in winter. Although these recommendations have been in the literature for some years, probably not more than a handful of working environments have been designed to meet them.

VII *Legislation*

Diverse regulations have been made for minimum thermal standards to be met in some working environments. This diversity reflects differences in industrial circumstances, in the criteria used to evaluate adverse effects of inappropriate thermal environments, and in the aims of those responsible for framing environmental regulations. Thus, target temperature conditions vary between industries, between countries, and between the states in America. In the United Kingdom, the Factories Act of 1961, Chapter 34, Part I contains provisions relating to air temperatures at places of work as follows:

Paragraph 3:

(1) Effective provision shall be made for securing and maintaining a reasonable temperature in each workroom, but no method shall be employed which results in the escape into the air of any workroom of any fumes of such a character and to such an extent as to be likely to be injurious or offensive to the persons employed therein.

(2) In every workroom in which a substantial proportion of the work is done sitting and does not involve serious physical effort a temperature of less than sixty degrees (15·5° C) shall not be deemed, after the first hour, to be a reasonable temperature while work is going on, and at

least one thermometer shall be provided and maintained in a suitable position in every such workroom.

(3) The Minister may, by regulations for factories or for any class or description of factory or parts thereof, prescribe a standard of reasonable temperature (which may vary the standard prescribed by subsection (2) of this section) and prohibit the use of any methods of maintaining a reasonable temperature which, in his opinion, are likely to be injurious to the persons employed, and direct that thermometers shall be provided and maintained in such places and positions as may be specified.

The Act also contains provisions relating to factory environments in which levels of relative humidity are important features. In Chapter 24, Part IV of the Act the following appear:
Paragraph 68:

(4) There shall be no artificial humidification in any room at any time when the reading of the wet-bulb thermometer exceeds seventy-two and a half degrees (22·5° C), or, in the case of a room in which the spinning of cotton or the spinning of merino or cashmere by the French or dry process or the spinning or combing of wool by that process is carried on, eighty degrees (26·7° C).

(5) There shall be no artificial humidification in any room at any time when the difference between the readings of the dry-(air) and wet-bulb temperature is less than that indicated in the table of humidity. [E.g. from a difference of 1·1° C at an air temperature of 10° C to a difference of 3·3° C at the air temperature of 30° C. This ensures that relative humidity is kept below about 90 per cent at lower air temperatures and below about 77 per cent at higher air temperatures.]

The British government appoints a Chief Inspector of Factories whose staff in Her Majesty's Factory Inspectorate are charged with the duty of ensuring that these, and many more, provisions of Factory Acts are complied with.

VIII *Cold Conditions*

The effects of exposure to cold have received less investigation than have the effects of exposure to warm or hot conditions. There are several possible reasons for this. Adding clothing may sometimes be more effective at low temperature than removing clothing at higher temperatures. Throughout industry, the vast majority of manufacturing processes generate a problem of heat rather than one of cold. Where a problem of cold does occur, it is often easily remedied by providing a local source of heating. Several studies have shown that an *apparent* problem of a cold environment is much less hazardous when the actual temperature under everyday working clothes is assessed. Where extreme cold is potentially hazardous to the well-being of workers and to their efficiency, they can be helped by protective garments including heated socks, gloves and suits, in addition to other garments with insulative properties. Thus in many work situations, it is more usual to protect the worker from the effects of exposure to cold rather than to investigate the effects that may occur in unprotected workers.

Loss of efficiency in manipulative activity has been found to correlate with low finger and hand temperature. The effect appears to be a local one in that loss of tactile sensitivity, reduction of hand-grip strength, or reduced joint flexibility appears to depend on skin surface and peripheral limb temperatures in the region of 10° C to 15° C rather than on reduced levels of internal body temperatures. Air temperatures below and within the range of 10° C to 15° C have been shown to produce some deterioration in a task that requires the worker to track a target by manipulating a control handle. The incidence of minor accidents in industry also appears to increase with reduction in air temperature to about these levels.

Data from clinical studies of the victims of exposure to cold appear to suggest that a critical level of body temperature of about 35° C exists below which distress becomes more and more marked. Old people, undernourished or thin adults or children, and infants below the age of about 12 months are particularly susceptible to reduced body temperature and its

consequent ill-effects. If steps are not taken to prevent body temperature from falling further, a decline in physical well-being may result which becomes increasingly difficult to reverse. At body temperatures of about 33° C, victims begin to lose their grasp of reality and there is mental confusion and a clouding of consciousness. If body temperature falls to about 30° C, the result is severe disturbance in cardiac functioning. At body temperature of about 25° C, death is almost certain. Treatment of an individual whose body temperature has been reduced to a hazardous level must be left to an experienced doctor. With exposure to relatively mild degrees of cold, the body's thermoregulatory mechanisms will tend to ensure that body temperature is maintained by shivering and other natural reactions leading to increase in, and conservation of, metabolic heat.

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CHAPTER 6

Environmental Qualities

The physical environment of men at work does not exist within an organisational, social or psychological vacuum. Nor is industry peopled by automata. Sometimes, applied scientists have been led, by an enthusiasm for reaching quantifiable equations of physical environmental parameters and worker performance effects, into a partial blindness to the presence of other potential influences in the work situation of a more qualitative, though no less tangible, nature. If a human science is laboratory based, if it uses engineering analogies, and if it takes physics as the paradigm of scientific discipline, then it is probable that such variables as organisational structure or control, attitudes or social norms of behaviour, and motivations or psychological perceptual distortions will be regarded as extraneous to the 'hard', quantitative, variables that belong 'properly' in scientific research. Although such 'soft' variables may be most important in achieving a better understanding of the behaviour of men at work in relation to their industrial environments, they may be totally ignored by some applied scientists.

I *Surprising Findings*

It would be useful to have a record of the frequency with which workers protest about some aspect of their physical environment at work. It would also be useful to classify the environmental factors that give rise to such protest and to explore the reasons for the complaints. Did the workers act spontaneously? Or were they supported by their official representatives? Whether

dissatisfaction with working conditions caused a 'token' protest, or the threat of a prolonged withdrawal of labour until conditions had been improved, might give some indication of the seriousness with which workers regarded the hazards from their environment. It cannot be assumed that workers place as high a premium on environmental factors as the investigator does. The frequency with which action is taken by workers when contrasted with the number of occasions when, under similar conditions, no action is taken, might throw light on the assumptions as to the importance of physical factors to working men. It might also indicate the extent to which influences other than physical ones affect the worker. For example, the attitude, to their job and to their employers, of the workers in a given firm, and their firm's history of union-management relations, may influence the extent to which action is taken to improve potentially adverse conditions. Many factors of a non-physical kind may intrude into the relation between workers and their physical environment. Some examples may illustrate this.

A study was made of the ability to monitor a bank of dials under conditions of extreme heat. During the experimental sessions, the men were seated before the dial display and they remained there until a limit of physiological tolerance was reached. The men were highly motivated to push themselves to the limit. During the first few days of the investigation, a strong competitive element arose among them to see who could withstand the heat for the longest times. On one occasion, the laboratory was visited by some dignitaries. The visitors agreed to stay in the background. The men, on that day, revealed a level of heat tolerance considerably in excess of that which could have been predicted from a knowledge of their previous responses. There had been no active encouragement from the visitors, but word had spread that the laboratory was being visited. The data from the day of the visit were so deviant from the data collected on other days of the investigation that they had to be disregarded.

Exposure to noise levels in excess of about 90 dB has adverse effects on the laboratory performance of tasks that require continuous attention over long periods of time. An opportunity

arose to examine similar effects, in an industrial context, when a firm making cine film requested advice on improving the efficiency of some of the workers. These men had operated machines that made perforations in the reels of cine film. The machines were very noisy. In one room in which about five operators worked, noise levels of between 98 and 99 dB were found. The investigators advised the firm to install noise absorbent material between the machines and over the ceiling and walls of the room. This reduced the noise levels by about 8 to 10 dB.

Performance of the workers was recorded before and after the noise had been reduced and, over a similar period, in another room where no reduction in the noise level had been made. In the work-rooms where noise had been reduced, there was an improvement in the rate of work. There were fewer calls for machine maintenance personnel. There were fewer broken reels of film and a reduced frequency of machine 'shut-downs'. There was also a slight reduction in absenteeism. Reduction of noise thus seemed to have had a marked beneficial effect. However, there was also an improvement in the performance of the operators whose noise environment had remained unaltered. They showed a better rate of work. They made fewer calls for maintenance staff. Machine 'shut-down' was less frequent. There was a modest reduction in absenteeism. There were slightly fewer broken reels. None of these changes was very different from the changes found in the work-room where noise had been reduced.

Studies conducted into the effects of extreme temperature might be expected to demonstrate an influence of the physical environment on human performance that is less susceptible to 'intrusive' variables. In fact, a study of the reactions, output and physiological responses of South African gold miners, under hot and humid conditions, showed that the kind of supervision received from their 'boss-boys' had an influence on the men's ability to withstand the extreme conditions. At the other extreme of temperature, it has been observed that the well-being, accident rates and efficiency of trawler fishermen in Arctic waters depends to some extent upon their confidence in

their trawler captains. Despite very severe cold, which has been shown in several studies to increase accidents and reduce efficiency, the crews of some trawlers appear to be less vulnerable, due to the kind of leadership given by their captain. In another environmental context, a report has been made of the physical conditions of work of a group of girls whose job was to sort offal in a slaughter-house, a most unpleasant, but not necessarily toxic, work environment. Such working conditions might have been thought to lead to a situation in which the girls would have a great distaste for their work and a desire to change to another, more congenial, job context fairly quickly. In fact, the girls had developed strong group feelings, were happy to continue in their work, and expressed satisfaction with the job they were doing.

In medical and pharmacological research and practice, there is a phenomenon called a *placebo* effect, which may be illustrated as follows: one group, in an investigation, may be given a drug and the other group is given a tablet that looks and tastes similar to the drug, but contains no active chemical or pharmacological ingredient (i.e. a *placebo*). The reactions of the two groups are compared in order to evaluate the effects of the drug being tested. Sometimes, *placebo* effects occur that must be taken into account in evaluating what proportion of effects are due to ingesting a tablet, taking part in the study or to the active constituents of the drug itself.

An effect, similar to that of a *placebo*, was found in a recent study of the effects of blood sugar level on working efficiency. Comparisons of performance were made between times when workers were given glucose drinks and when they were not given any drinks. Performance under the former conditions was superior to that under the latter. However, during one of the 'dry' periods, a glass of plain water was given by mistake. Performance after that glass of water was found to be better than after a glucose drink. Another finding was that comparable improvements in performance were produced in two groups, one of which had been given glucose drinks and the other had been given drinks not containing any glucose.

Finally, a study may be cited in which an unexpected *effect*

of exposure to adverse conditions became an *influence* on the responses of other men to those conditions. Exposure to extreme forms of thermal stress has been occasionally reported to give rise to marked emotional reactions. In a study of physiological reactions to very high temperature, one of the workers began to show signs of irritation, annoyance and aggression. He appeared to be suffering no more strain on that day than on previous days and he seemed, physiologically, to be no more close to a tolerance limit than any of the other men in the same environment. However, as his exposure continued, the man became increasingly agitated. He began shouting abuse at the observers and investigators, who were monitoring his approach to heat collapse so as to protect him from danger. His abuse was also directed to the other men who were taking part in the study and who were being exposed to the environmental stress at the same time. Before long he attempted to wreck the laboratory.

All the men taking part in the investigation had volunteered and knew that, although it was desired that they push themselves to their physical limit of endurance, they were free to withdraw at any time. Indeed, on some occasions, they were asked to leave because the observers, who were monitoring their progress, judged that their limit of tolerance was fast approaching, whether then men felt unwell or not. As this individual became emotionally disturbed the observers encouraged him to withdraw. He not only refused to leave but threatened dire consequences to anyone who tried to get him out. Eventually, he reached a state of near collapse and was removed.

The following day, he apologised for his behaviour and admitted that he had not known 'what had come over' him. He expressed a strong wish to continue taking part in the investigation and said he would feel very upset if he were prevented from doing so. He was therefore allowed to remain. That day, two other men began to show emotional responses to their stressful environment. By the end of the week, several men were expressing similar reactions. Such behaviour had not previously been observed and during the following week there were no signs of emotional disturbance. There may be many

other examples, such as this and the others described, of an unexpected factor appearing during investigation of men at work and the influence on them of their physical environment.

II *Hawthorne Effects*

During the first two decades of this century, work was carried out, by the Department of Industrial Research at Harvard, to identify environmental sources of worker fatigue and to suggest ways in which an improvement in output could be attained by improving working conditions. In 1923, one of the staff at Harvard, Elton Mayo, was called upon to advise the owner of a textile mill in Philadelphia. In the mill, there was a labour turnover of about 250 per cent per annum and considerable under-productivity among mule-spinners. Mayo examined the situation and suggested that the source of the difficulties lay in 'postural fatigue and impaired circulation arising from the monotony of the job' coupled with the fact that as 'everyone, worker or executive, probably carries with him a private grief or discontent, whenever the conditions of work are unsuitable, physically or mentally, the immediate effect seems to be an increase of pessimistic or bitter reflection'.

Two rest pauses were introduced to break the monotony of the work. In order that an estimate of the effect of the rest pauses could be made, they were given only to one third of the mule-spinners. Mayo's hypothesis concerning the cause of the problem appeared to be confirmed when the one third of the mule-spinners who had been given the rest pauses improved their productivity. He was surprised to find that the other two thirds of the mule-spinners, who had not been granted rest pauses but whose output had been monitored in order to provide a basis for comparison, had shown a similar improvement in productivity.

Shortly afterwards the firm received a rush order and the supervisors of the spinners decided that the times given for rest pauses could not be 'wasted'. So they were cancelled. Productivity fell dramatically. The supervisors, therefore, realising their mistake, reintroduced the rest pauses, with the proviso that

they could be taken only after a specified quota of work had been completed. Productivity stayed low and labour turnover began once more to increase. Mayo now suggested that the supervisors be overruled and the rest pauses reinstated in their original form. The owner acted upon this advice and ordered that the machinery be shut down twice a day whilst the workers enjoyed their ten-minute rest pauses. Improvements were rapid and marked. The workers were asked to voluntarily stagger their rest pauses so that the machinery could be run continuously throughout the working day. This was agreed and productivity was unaffected. With this system in operation, production was maintained at 125 per cent of its pre-Mayo level and labour turnover was reduced to about 5 or 6 per cent per annum.

A year or so later at the Hawthorne Plant of the Western Electric Company in Chicago, the lighting conditions of one group of workers were improved and output compared with that of another group of workers whose lighting had not been changed. The productivity of both groups increased and was maintained, even when the lighting standard of the first group was returned to its original level. In another part of the plant, a piece-rate bonus scheme had been introduced to encourage a group of workers to increase their output by using this opportunity of earning more money. The 'incentive' payment scheme had no effect on output, despite the fact that the management were convinced that the workers could have increased their output with an extra effort well within their physical capabilities.

Mayo was invited to attempt to solve these problems. In 1927, he set up two investigations at the Hawthorne Plant. In one of these, two girls were invited to choose four colleagues to form a team to assemble and inspect telephone relays. Subsequently, two of these girls were replaced by faster workers. At the beginning, the girls worked a 48-hour week, finished work at 5 p.m., had no rest pauses, were on a flat-rate wage and produced about 2,400 relays a week. Piece-work payment was introduced for a period of eight weeks and output went up. Two rest pauses, of five minutes each, were given daily over the next five weeks and output went up again. The rest pauses were lengthened to ten minutes each and a hot snack was provided

in the mid-morning pause. Output went up further. The working day was then shortened to end at 4.30 p.m. and output increased. A further shortening of the working day was introduced, so that it ended at 4 p.m., and the level of output was maintained. Finally, the girls' working conditions were returned to the original form of a 48-hour week, 5 p.m. finish, no rest pauses, and a flat-rate wage. Output during the twelve weeks of this final phase of the study was the highest recorded throughout the investigation. It had reached about 3,000 relays per week.

The second study concerned nine wiremen, three solderers, and two inspectors, who were maintaining a ceiling on output in a bank wiring-room, despite the offer of higher earnings for increased output. The investigators observed the workers at their jobs and conducted individual interviews with the men away from the work-place. The study showed that there existed well-established norms for acceptable output for the group as a whole and for each individual member. If output fell below these norms, dismissal was a possibility, and if output rose above these norms, an effective cut in the rate for the job would occur. In order to avoid dismissal and maintain their rate for the job, considerable pressure was brought to bear on individual members of the group to maintain the level of output that was expected of them. These pressures also operated to prevent the men from betraying the group to the management. The two inspectors were tolerated as peripheral group members as long as they avoided 'swankiness', 'bossiness', 'superiority' or 'edge'.

Several interpretations have been given of these 'Hawthorne effects' – as evidence for the importance of the workers' attitudes or expectations, as 'experimenter effect', as a sign of motivation for group membership, as an indication of workers' need for esteem, as evidence for the effectiveness of group pressures, and so on. There has been much criticism of the Hawthorne investigation and the conclusions that have been drawn from it. However, whatever its defects and limitations, it did produce some surprising results and, more important, it heralded the beginnings of a new approach to the study of men at work. This has sought to eliminate 'surprise' elements from studies of the effects of physical environments on men at work and replace them

with predictions and expectations based upon a better understanding of the total work context.

III *Social and Organisational Studies*

There have been, since Mayo, many studies of industrial status hierarchies, communication networks, decision-making strategies, leadership styles, formal and informal work groups, managerial human relation skills, dispute procedures, worker participation schemes. Managers have come to be regarded more as men-manipulators rather than environmental engineers. To some extent, a view of man as a component in a social system is coming to replace the view of man as a component in a physical system. Interest in the man-environment interface is giving way to interest in the man-organisation interface. The rise of social and organisational studies of men at work, alongside the study of workers' physical environment, may reflect a broader training of younger research workers. If, however it is a product of a change from one narrow emphasis to another, a synthesis of specialist approaches to the study of men at work will become more difficult. Only a few investigations have attempted to make comparisons of the influences of physical and non-physical factors on men at work.

One aspect of these studies that is of relevance to the main theme of this book is the relation of the physical environment to the motivation, satisfaction and performance of workers. The actual conditions in which men work are usually given a low priority in studies of workers' motivations. It has been shown, in respect of some classes of workers, that there appear to be two classes of environmental influences upon men at work. One class relates to the physical and organisational features of the working environment. These are called 'job hygiene' or 'job context' factors. If these characteristics are felt by the workers to be inappropriate, dissatisfaction is experienced. When they are suitable, they are hardly mentioned at all. A well-designed environment appears to be rarely regarded by the workers as a source of satisfaction. It does not seem to increase motivation to work. The other class relates to the job itself and the individual's

pride, sense of achievement, or attainment of advancement in his job. When he feels he is doing well, and getting somewhere, the worker tends to express feelings of satisfaction. He less frequently mentions not doing well, and getting nowhere, when describing features of work that lead to dissatisfaction.

Although, in recent years, there has been a decline in the importance attributed to physical conditions of work as motivators for increased efficiency, the investigations giving rise to this shift in emphasis, away from physical environmental conditions, are not without their limitations. First, there has not been a comprehensive sampling of varieties of work. In fact, the range of jobs, from which conclusions regarding the minor importance of working conditions have been drawn, is relatively narrow. In some of the jobs chosen for study, it has emerged, for instance, that salary is relatively unimportant to the worker. This does not appear to be reflected in much of the activity of union-management negotiators in many other sections of industry.

Second, little attention has been paid to the possible symbolic significance of some of the physical factors. Some workers may regard their physical environment as an indication of their ability to perform 'real' work. When there are attitudes of contempt for the 'pen-pushing' work-force, it may be that hot, dark, grimy conditions, and the workers' ability to tolerate the stresses these conditions impose, may be seen as evidence for the 'toughness and masculinity', required in those situations. The occasional irrational resistance encountered to the introduction of protective devices may derive, in part, from the contribution of stressful physical conditions of work to the image of the job and to the self-image of the workers.

Third, physical conditions of work may be of great importance to men in those sections of industry in which threats to safety and survival are seen to come from inappropriate environmental conditions. In these cases, the physical environment may be given a high priority as a source of dissatisfaction. When the conditions have been improved and their threat removed, the improved conditions may be, for a time, a source of satisfaction to those who had previously seen them as a threat.

Fourth, in some studies, the features that were sources of dis-

satisfaction and complaint were seen by the workers as the responsibility of others. When satisfaction was felt, the worker tended to associate this with features of the work for which he was directly responsible. Thus one set of features appeared to relate to dissatisfaction and a different set of features related to satisfaction. This may be due to a tendency for people to blame others for creating dissatisfaction, at work or in any other sphere of life, and to credit themselves with responsibility for any satisfaction they feel.

The view of man taken in studies of physical, social and organisational aspects of the environment has often been parochial. Enquiries into man's moral and social values, his philosophy of life, his aspirations and fears, the integration of work with other aspects of life, have been neglected in the investigation of men at work. Even within a narrowly defined industrial location, it is unusual to find any situation in which all possible environmental characteristics of a social, organisational or physical nature, except one, may be eliminated from consideration because they are innocuous. Yet despite the complexity of the reality, very few studies have examined the effects of two or more environmental factors acting in combination. There are many reasons why there have been few attempts at comprehensive investigation of men at work. Analytic approaches to research, in which the goal is the determination of the variables in any given situation followed by their isolation and close study, tend to predominate. Industrial clients tend to look for simple, straightforward recommendations. Often, an investigator must compromise between what is acceptable to his client and what he feels to be important in achieving an understanding of the influences on men at work. If a basic characteristic of men at work is their culturally, occupationally, and environmentally determined variety, what is required appears to be more sophisticated analyses of that variety. Until such an exercise is undertaken, the formulation of a general theoretical framework encompassing the complex interaction of men at work with their physical environment is not possible.

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Men at Work presents a broader and more complete picture of the influence of industrial environments than other textbooks to date. A wide variety of occupations is examined, stressing the individuality of the worker – for, although the effects of lighting, noise, space and temperature are analysed and described in detail, the author emphasises that physical surroundings are not everything and that people often have strong and unexpected feelings about their work-place.

Men at Work reflects Clifford Bell's research both as a psychologist and social scientist. An ideal introductory book for students of environmental and industrial psychology, ergonomics and physiology, it should appeal too to scientists, technologists, industrial consultants at the frontiers of laboratory and workshop, and also to managers, personnel officers and trade unionists.

Clifford Bell was born in 1934 in Barrow-in-Furness, a shipbuilding and engineering town in the north of England. After National Service in the RAEC from 1952 to 1954, he studied psychology at the University of Sheffield where he gained a BA Honours degree in 1958. His subsequent career has encompassed research posts in the London School of Economics, the University of Oxford and the London School of Hygiene. For eleven years Dr Bell was a scientific member of the Medical Research Council during which time he published many research papers on environmental influences upon working efficiency. He was awarded a PhD degree by the University of London in 1969. The following year he joined the teaching staff of the Department of Psychology at Manchester University where he lectures on industrial psychology. He is a member of the British Psychological Society, the International Association of Applied Psychology and the Ergonomics Research Society.

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